Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work

b) load data from another user by typing in the ‘Save Code’

c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Designing Solutions: Slowing Down Heat Transfer

Timing: one 90-minute class session

Objective(s):
In this activity, students are asked to determine the best material with which to insulate an airplane cabin from the extremely cold temperatures that are typically encountered at high altitudes. They will model the airplane as a small empty beaker encased in a variety of different insulating materials. By placing this model system in an ice water bath and measuring the resulting change in temperature of the air as a function of time, the students will investigate how quickly heat is lost and determine the material that most effectively impedes heat transfer.

Safety Precautions:
- Follow all lab safety guidelines.
- Be careful in handling glassware.
- Wear closed-toed shoes, safety goggles, and a lab apron to protect from spills or splashes.
- Notify the instructor immediately if you see any broken glass. Do not try to clean it up yourself.
- Tie back long hair.
- Do not eat or drink anything in the lab.

Materials:
Per group:
- polystyrene foam mat
- beaker, 150 mL
- beaker, 250 mL
- beaker, 1000 mL
- lid, with small hole
- sand
- polystyrene foam balls, small
- metal shot, steel
- sand
- water
- ice
- thermometer
- timer
- graduated cylinder
Teacher Preparation:
- Gather materials in advance of students performing the lab.
- Combine the ice and water to make an ice bath before the start of the lab and periodically add more ice to the bath during the experiment.
- Sand, metal, and foam are only suggested test materials. Other materials such as plastics, liquids, or mixtures of materials could also be investigated.
- If 150 mL, 250 mL, and 1000 mL sized beakers are not available; other small, medium, and large beakers may be used as long as the small beaker fits inside of the medium-size beaker with only a small space between the two; and the large beaker has a much greater volume than the other two.

Procedure
1. Place the small beaker inside of the medium-size beaker. Fill the space between the two beakers with the metal shot. This two-beaker combination is the model airplane system. Place the lid on the system and insert the thermometer into the hole in the lid.
2. Fill the large beaker with ice water. Place the model airplane system inside the ice water bath. Make sure that the level of the ice water doesn’t go above the height of the model airplane system.
3. Measure the starting temperature of the air inside of the small beaker in a table similar to the one below. Record the temperature to the nearest tenth of a degree.
4. After 1 minute, record the new temperature inside of the beaker.
5. Repeat this process 14 more times for a total time of 15 minutes.
6. Remove the model airplane system from the ice bath and carefully pour the metal shot back into the original container. Dispose of the ice and water.
6. Graph the temperature inside of the beaker as a function of time. The time is the independent variable and should be placed on the horizontal axis. The temperature is the dependent variable and should be placed on the vertical axis.
7. Repeat the procedure using the small foam balls and then the sand. Also repeat the procedure without using any insulating material.
8. Plot all data on the same graph in order to qualitatively compare the cooling rates for each of the insulating materials.
9. If time allows, students may also investigate the use of different mixtures of foam and metal as insulating material in order to simulate the effect of a metal airplane hull insulated with foam.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
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<td>1.0</td>
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<td>7.0</td>
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<tr>
<td>8.0</td>
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</tbody>
</table>
Table 2: Time and Temperature Table with Sample Student Data

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>22</td>
</tr>
<tr>
<td>1.0</td>
<td>19</td>
</tr>
<tr>
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<td>14.0</td>
<td>4</td>
</tr>
<tr>
<td>15.0</td>
<td>4</td>
</tr>
</tbody>
</table>

Analysis and Conclusions

1. Use your graphs to qualitatively describe how the temperature inside of an unheated airplane cabin changes as a function of time. [Initially, the temperature in the airplane cabin drops quickly. As the temperature inside of the cabin approaches the outside temperature, the rate of change of the temperature slows.]

2. Why does the temperature inside of the cabin change? [Temperature is a measure of thermal energy. Since the air molecules have more thermal energy than the molecules in the cold air modeled by the ice bath, heat flows out of the "airplane cabin." This heat transfer results in a decreased temperature inside of the cabin.]

3. How does the use of insulating material affect the temperature change inside of the cabin? [The insulating material will slow the rate at which heat is transferred out of the system.]
4. Which material does the best job of insulating the cabin? Why? [Answers may vary depending on the experimental results but should reflect the insulator that resulted in the slowest rate of heat transfer. The most likely answer is the foam insulation.]

5. Why did you perform an experiment without insulating material? [The uninsulated experiment is the scientific control for the experiment. It is used to account for the effect that other variables might have on the experiment.]

6. As the temperature inside of the beaker decreased, heat was transferred out of the system. Where did it go? [The heat was transferred to the surroundings, the ice bath, where it caused some of the ice to melt.]
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - asks a question about a specific science concept or process
    - can be answered with a science investigation or observational study

- **Design Investigations**
  - Design and conduct investigations using:
    - Control (control group)—used for comparison in which the independent variable is not changed
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use

- **Gather Data**
  - Uses Tools and/or the Use SI (metric) system to accurately measure:
    - Temperature
  - Chooses appropriate tools to conduct an investigation
    - Glassware
    - Thermometer
  - Uses the appropriate format to record data:
    - Table
    - Graph or chart

- **Interpret Data**
  - Identifies and interprets patterns
    - Trends in data
    - Repeating physical or data pattern
    - Graphed data points

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Comparing results to hypothesis
    - Extrapolating results beyond the investigation

- **Scientific Investigation**
  - Scientific Investigation
    - Science investigation begins with a testable question.
    - Scientific investigation leads to more questions.
  - Scientific Data and Outcomes
    - Collecting and analyzing data is the best way to understand a changing pattern.
Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.

- **Scientific Endeavor**
  - **Characteristics of Science**
    - Science is based on factual knowledge.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
    - An important part of science is the critical review and analysis of any idea or conclusion.

- **Engineering and Technology**
  - **Engineering Design**
    - Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
Overview

Heat energy always transfers from a hotter object to a cooler one. During this process the temperature of both objects changes until the temperatures become equal. In this Exploration, students observe the transfer of heat energy between two objects. Students also examine the change in temperature of two objects as they achieve thermal equilibrium.

Student Learning Objectives

- Analyze the change in temperature of two objects placed in contact with each other.
- Investigate the variation in heat energy of two objects with change in their temperature.
- Examine the change in the speed of molecules in an object as its temperature changes.
- Observe the transfer of heat energy between two bodies.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, two objects of different materials are displayed. These objects are placed in thermal contact with each other. Students select the material and initial temperature of both objects using the Object 1 and Object 2 sections. Using options in the Select Material dropdown lists, students select the material of the objects. Students select the initial temperature of each object using options in the Select Temperature dropdown lists.

When the students click on the Start button, a zoomed in view shows the motion of the molecules in both objects. Molecules of the object with higher temperature vibrate with a greater speed and the molecules of the object with lower temperature vibrate with a lesser speed. Heat is transferred from the hotter object to the cooler object until the objects reach thermal equilibrium. The values of the temperature and heat energy of both objects are displayed below the objects and in real time while the simulation runs.

Using the Reset button, students can reset the Exploration and observe the heat transfer for a different selection of object materials and temperatures.

The Data tab displays the values for the current run. Students can observe the heat energy and temperature of both objects at different intervals of time. Heat energy is displayed in both Joules and calories.
The *Graph* tab displays graphs of heat energy versus temperature and average molecular kinetic energy versus temperature. Students can use options in the *Select Graph* dropdown list to select a graph. These graphs can be used to examine the heat energy and average molecular kinetic energy of both objects for different values of temperature.

The *Tracker* tab displays a summary of the values for all the runs. Students can observe the values of equilibrium temperature and the final heat energy of both objects.

**Answers to questions in the Student Worksheet**

1. Determine whether the kinetic energy of molecules of an object and its temperature are related. Explain your answer.

   **Answer:** Yes, the kinetic energy of the molecules of an object and its temperature are directly proportional. The kinetic energy of the molecules of the object increases with an increase in temperature.

2. Explain the term thermal equilibrium.

   **Answer:** Two objects are said to be in thermal equilibrium when their temperatures are equal.

3. In the Exploration, select different temperatures for the two objects. Then select different materials for each object and run the simulation multiple times varying the materials used each time. Observe and explain the effect on the equilibrium temperature of both objects. Use the *Tracker* tab to view a summary of all of the runs.

   **Answer:** The value of the equilibrium temperature changes with the material even if the initial temperature for successive runs is kept the same. If the same material is selected for both objects the equilibrium temperature is the average of the value of two selected temperatures.

4. In the Exploration, select the same material for the two objects. Then select different temperatures for each object and run the simulation multiple times varying the initial temperatures used. Observe and explain the effect on the equilibrium temperature of both objects. Use the *Tracker* tab to view a summary of all of the runs.

   **Answer:** The value of the equilibrium temperature changes with the temperature even if the material selected for successive runs is kept the same. Different materials transfer heat at different rates and so the equilibrium temperature is different in each case.
5. Determine whether the transfer of heat energy depends on the material. Explain your answer and include a real-world example.

**Answer:** Yes, the rate of transfer of heat energy will be greater for an object which is a good conductor of heat. Consider an example where you are boiling water in a metal utensil with a handle coated with rubber. The degree of heat experienced by a person is greater if he/she touches the utensil than when he/she touches the rubber handle. This is because metal is a better conductor of heat than rubber.

6. An experiment is carried out to observe the melting of ice. Heat energy is supplied at a constant rate. The temperature of the ice is recorded at different intervals of time. After some time, the observed values of temperature become constant even though heat energy is supplied to the ice. Explain what is happening in this situation.

**Answer:** The temperature becomes constant after some time because the supplied heat energy is utilized for changing the phase of ice.

7. Determine if the following statements are true or false. If a statement is false correct it so that it is true.
   a. In nature, the direction of the transfer of heat energy is always from a hotter object to a colder object.
   b. Calorie is a unit of temperature.

**Answer:**
   a. True.
   b. False. Calorie is a unit of heat energy.

8. Calculate the amount of time required to raise the temperature of 0.50 liter of water from 0.0°C to 10.0°C if heat energy is supplied at a rate of 1100 joules per second.

**Answer:** The amount of heat required to raise the temperature is given by the following formula.

\[ Q = m \times c \times \Delta T \]
\[ Q = 500 \text{ g} \times 1 \times 10.0^\circ \text{C} \]
\[ Q = 5000 \text{ calorie.} \]
\[ 1 \text{ calorie} = 4.184 \text{ J.} \]
\[ 5000 \text{ calorie} = 20920 \text{ J.} \]

Heat is supplied at a rate of 1100 Joules per second.
Time required to supply 20920 J of heat energy = \( \frac{20920}{1100} \approx 19.01 \) seconds ≈ 19 seconds.
9. Define calorie and explain the difference between a Joule and a calorie.

   **Answer:** A calorie is defined as the heat energy required for raising the temperature of 1 g of water by 1 °C. A Joule can also be used as a unit of heat energy. 1 calorie = 4.184 J.

10. Determine if the following properties of an object affect the heat energy transferred by it. Answer Yes or No in the space provided after each property.

    a. Temperature of the object     ________
    b. Surface area of the object    ________
    c. Temperature of the surrounding material ________
    d. Material of the object        ________

   **Answer:**
   a. Yes
   b. Yes
   c. No
   d. Yes
Hands-On Lab
Newton’s Law of Cooling

Timing: one 90-minute class session

Objective(s):
Students will use data acquisition probes to follow cooling of warm muffins over time

Safety Precautions:
Avoid burns from either a hot muffin or a hot muffin pan. Remind students to follow all general lab safety rules, wear closed-toe shoes, and not to eat or drink anything in the lab.

Materials:
Per group:
- ring stand
- clamp
- temperature probe
- tape, electrical or masking
- muffin, hot (or warm)
- tongs, baking, or oven mitt and fork
- watch
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- The temperature probe should be connected to a digital or analog readout for easy temperature readout.
- If your school’s lab is not equipped with probes that connect to a computer or graphing calculator, a meat thermometer is a good example of an inexpensive temperature probe. These have a built-in analog or digital temperature readout, a meter or display on the end.
- Bake muffins in an oven for ease of handling.

The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome. You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry

Students should be familiar with Newton’s Law of Cooling, which describes how quickly a hot object cools to the temperature of its surroundings. Familiarize your students with a temperature probe and how to use it.

Muffins should be brought from oven, and may be carried into the classroom in an insulated box, to avoid the burn dangers associated with bringing a hot muffin pan into the room.

Procedure

1. Have students attach clamp to ring stand.
2. Note temperature measured by temperature probe.
3. Hold probe in clamp, taping it in place if necessary. Try to align probe readout for easy reading.
4. Use tongs or fork to place muffin on ring stand from either tin or insulated box.
5. Insert probe into center of muffin, and adjust clamp to hold probe in place.
6. Every thirty seconds after inserting probe, students should read temperatures measured by probe.
7. Students should make a chart of probe temperatures. A chart might look like this:
8. Continue taking probe measurements for fifteen minutes.

Students should graph their data from this experiment. If a computer spreadsheet program is available, students should insert a trend line, which is a curve fit to their data. If they do, have them report on both the curve fit itself, and the $R^2$ parameter, which is a function of how closely the curve fits the data. (Consult your spreadsheet or graphing calculator’s help file or manual for information on the coefficient of determination.) Newton’s law of cooling uses an exponential function, and students will obtain their best value of $R^2$ (i.e., closest to unity) for a curve fit that is exponential with respect to time. If students subtract out room temperature measured by the probe in Step 2 before curve fitting data, $R^2$ will come closer to unity than for a curve fit of raw data.

**Guided Inquiry**

Students may try different methods to keep the muffin warm for longer, such as surrounding the muffin (including space above and below it) with foam packing pellets in a plastic bag, or surrounding it with other insulating material. Alternately, they may try to drive up heat convection by repeating this lab with a desk fan trained on the hot muffin.

Students may be curious about the cooling properties of other things than a hot muffin. Repeating this lab with hot water may give different results, as hot water may not cool according to Newton's law of cooling. Heat losses from a hot fluid are partly due to conduction and partly due to convection. In general, convection may remove heat energy at a rate that is consistent with the temperature difference between the water and its surroundings. Moving air, however, will help to remove heat energy at a faster rate, and cooling may occur faster than predicted by Newton’s law of cooling.

Repeating this lab with a different-sized baked item (i.e., several probes inserted into a freshly-baked loaf of bread, for example) may serve to illustrate the relation between temperature and thermal energy, and what parts of such an item cool soonest.
Analysis and Conclusions

1. What happened to the temperature measured by the probe over time? Why did you note the probe’s measurement in Step 2, before you added water to the beaker? The Step 2 temperature was room temperature, which the probe temperature approached over time. We curve fit the probe temperature to an exponential function over time, and obtained an excellent fit to this data after we had subtracted out the Step 2 temperature.

2. Name the two processes by which thermal energy was lost from the muffin, and compare and contrast them. Conduction moved heat from the muffin into the ring stand. Convection moved heat from the muffin and the ring stand into the air in the room. While conduction is simply vibrating molecules transferring energy by hitting other molecules, convection has a fluid sweep by, absorb heat, and rise to carry it away.

3. Name two ways that heat loss from the muffin would change if you redid this lab with a desk fan blowing upon the muffin. Heat loss would speed up, and the muffin would cool to a slightly lower temperature than room temperature.

4. How might someone keep a cup of coffee hot for a longer period of time? Name two ways, and explain why both work. (1) Keep it in an insulated cup or bottle so that thermal energy is lost more slowly. (2) Keep it in a pot with several other cups of coffee so heat losses from the pot can be averaged over all cups.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop a question that:
    - Asks a question about a specific science concept or process.
  - Recognize and develop testable questions that
    - Can be answered with a science investigation or observational study.

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Survey: compares changes in data points over time.
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Control (control group) - used for comparison in which the independent variable is not changed
  - Make or use models that
    - Function exactly like or similarly to the real thing.
    - Allow the testing of a hypothesis with results that can be extrapolated to the real thing
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use Tools and Use SI units to accurately measure temperature
  - Uses senses to observe: Seeing
  - Uses a chart and a graph to record data.

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - Comparing results to hypothesis
    - Answer the testable question

**Nature of Science questions:**

- **Patterns and Systems**
  - Patterns and Change
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- **Scientific Investigation**
  - Scientific Investigation
  - Scientific Data and Outcomes
    - Some data can be collected in a short period of time (e.g. motion of a rolling ball) and some data takes much longer (e.g. the growth of a tree).
    - It is important in science to keep honest, clear, and accurate records.

- **Engineering and Technology**
  - Uses of Technology
Computers have sped up and extended people’s ability to collect, store, compile, and analyze data; prepare research reports; and share data and ideas with other investigators.
Hands-On Lab
Specific heat

Timing: one 90-minute class session

Objectives:
In this activity, students will predict the equilibrium temperature of water and a piece of metal in a calorimetry experiment. Then they will extend this to water and other pieces of metal of equal mass.

Safety Precautions:
The students will be boiling water, so they should be reminded to be careful in handling instruments and to use tongs to handle hot metals or the beaker of boiling water. Students should be reminded the day before the experiment to wear closed-toed shoes. In the lab, goggles and lab apron must be worn to protect from spills or splashes. Tell students to notify you immediately if they see any broken glass and not to try to clean it up themselves.

Materials:
Per group:
- 1 polystyrene foam cup
- equal masses of several metals (e.g., aluminum, copper, iron)
- 250 mL water
- 1 100-mL graduated cylinder
- 1 Bunsen burner
- 1 beaker (200 mL or slightly greater)
- 2 thermometers
- 1 pair of nonmetallic tongs
- 1 ring stand with ring

Per class:
- 1 triple-pan or electronic balance

Teacher Preparation:
Separate the class into small groups before doing the activity. Gather the needed materials a few days before the activity. Also, prepare a copy of the Student Investigation Sheet for each of your students before doing the lab activity.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to devise a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Demonstrate to the class the procedure of how to do a calorimeter experiment using polystyrene foam cups. Ask for some volunteers to record data, be in charge of the thermometer, and look after the boiling water.

1. Measure 150 mL of tap water into the graduated cylinder. Pour the 150 mL of water in a beaker (volume 200 mL or slightly larger). Place the beaker into the ring stand, secure it safely, and heat the water until it begins to boil using the Bunsen burner.
2. Measure the mass of the metal piece using the balance.
3. Using nonmetallic tongs, gently place the piece of metal into the boiling water and leave it there while you are performing steps 4–7.
4. Measure the mass of the polystyrene foam cup using the balance. Have an assigned member of the group record the mass.
5. Measure 100 mL of tap water into the graduated cylinder. Pour it into the polystyrene foam cup.
6. Measure the mass of the polystyrene foam cup with the tap water. Then calculate the mass of the water by subtracting the mass of the cup from the mass of the cup with water. Record the mass of the water.
7. Measure the temperature of the tap water. Record the temperature as the initial temperature of the tap water.
8. Measure the temperature of the boiling water with the piece of metal in it. The piece of metal will have the same temperature as the water, so record this as the initial temperature of the metal piece.
9. Using nonmetallic tongs, retrieve the piece of metal from the boiling water and transfer it directly into the cup of tap water.
10. Monitor the temperature reading of the water in the polystyrene foam cup and record the temperature when it stabilizes at a maximum value. This is the final temperature of the water and the piece of metal at thermal equilibrium.

Lead a discussion for the class by asking them:
• Can we assume that the energy of our system is conserved? (Yes. Only a very small amount of energy will have been lost from the polystyrene foam cup.)
• When the piece of metal was transferred from the boiling water into the cup of tap water, which object in our system lost some of its thermal energy? *(the piece of metal)*
• Which object gained or absorbed energy? *(the water)*
• What do you think will happen to the final equilibrium temperature if another object is immersed in boiling water and then transferred into the cup of tap water? *(The temperature may be higher or lower, depending on how much thermal energy the other object absorbs from the boiling water.)*

Instruct students to find out what will happen if they use the same mass of another metal for the experiment. Have them predict if the final equilibrium temperature of the new metal piece/water mixture will be larger, the same or smaller than the final equilibrium temperature of the first metal piece/water mixture. Have them find out the final equilibrium of the new metal piece/water mixture using the steps that you just demonstrated.

Encourage students to record their observations, hypothesis, and data in their notebooks. Remind them to record data using metric units and to use the rules of significant figures in their calculations. A portion of their data could look like this:

<table>
<thead>
<tr>
<th>Substance</th>
<th>Mass (Kg)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cup</td>
<td>m_c=</td>
<td></td>
</tr>
<tr>
<td>Cup and Water</td>
<td>m_{cw}=</td>
<td></td>
</tr>
<tr>
<td>Tap Water</td>
<td>m_w=</td>
<td>Initial Temp (T_w)=</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Temp (T_{w_f})=</td>
</tr>
<tr>
<td>Aluminum</td>
<td>m_{Al}=</td>
<td>Initial Temp (T_{Al})=</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Temp (T_{Al_f})=</td>
</tr>
</tbody>
</table>
Encourage students to compare their results with other groups. Then, instruct them to compare their experimental results with theoretical values by using the law of conservation of energy and the equation \( Q = mc\Delta T \).

**Guided Inquiry**

Have students view the video segment Calorimetry. Then, briefly demonstrate how to use the polystyrene foam cup in a calorimetry experiment. Boil 150 mL of water in a beaker (~200 mL or slightly larger) by using a Bunsen burner. Measure the temperature of the boiling water, and soon thereafter carefully place a metal object into the boiling water and leave it. After several minutes, remove the metal from the boiling water and transfer it into a polystyrene foam cup with 100 mL of tap water, the temperature of which has also been measured. Obtain the final equilibrium temperature of the metal/water mixture. Explain that the energy lost by the metal goes into changing the temperature of the tap water.

Inform the class that they will try to predict if using a different metal piece of identical mass will yield a larger, smaller or identical change in the temperature of the tap water. In order to help students develop their own procedure for collecting data, ask them some guiding questions to help focus their inquiry.

- How will you determine the volume of the water? (*Use a graduated cylinder.*)
- How will you determine the mass of the tap water? (*Using the balance, first measure the mass of the polystyrene foam cup. Then, measure the mass of the polystyrene foam cup with tap water. Take the difference between these two measurements to obtain the mass of the tap water.*)
- How will you determine the initial temperature of the tap water? (*Use a thermometer.*)
- How will you make sure that the initial temperature of the metal object is at a distinct temperature? (*Immerse for several minutes in boiling water.*)
- How will you determine the equilibrium temperature of the piece of metal and water? (*Use a thermometer in reading the final temperature of the metal/water mixture.*)
- How can you be sure that thermal equilibrium has been reached? (*When the temperature reading has reached a maximum and has stopped changing.*)

Have students present to you their procedure before allowing them to start. Their procedure could be as follows:

1. Measure 100 mL water.
2. Measure the mass of the piece of aluminum.
3. Get the mass of the polystyrene foam cup. Place 100 mL water into the polystyrene foam cup. Measure the mass. Take the difference between the two masses.
4. Measure the initial temperature reading of the tap water.
5. Boil some water. Measure and record the temperature of the boiling water.
6. Immerse the aluminum in the boiling water.
7. After several minutes, remove the aluminum from the boiling water.
8. Immerse the aluminum in the tap water. Monitor the temperature of the aluminum/water mixture. The highest constant temperature is the equilibrium temperature.
Encourage students to record their observations, hypothesis, and data in their notebooks. Remind them to record data using metric units and to use the rules of significant figures in their calculations. Their table can look like this:

<table>
<thead>
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</thead>
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<tr>
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<td></td>
<td>Final Temp (T_{wf})=</td>
</tr>
<tr>
<td>Aluminum</td>
<td>m_{Al}=</td>
<td>Initial Temp (T_{Al})=</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Final Temp (T_{Alf})=</td>
</tr>
</tbody>
</table>

Encourage students to compare their results with other groups. Then, instruct them to compare their experimental results with theoretical values by using the law of conservation of energy and the equation $Q = mc\Delta T$. Provide students with values for the specific heat, $c$, of the various metals used.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What new questions were you able to generate from this lab activity? How can you extend this lab activity in order to answer your questions? *(The results made us think about using other objects for the activity. We can extend this activity by using other objects with different specific heats.)*

2. How can you explain the differences in your results from those of other groups? *(The variations may be due to the specific steps that we did in order to come up with our results. For example, the groups may differ in the time it took them to transfer the metal from the boiling water to the tap water.)*
3. Why did you use a polystyrene foam cup for this activity? *(We used a polystyrene foam cup in order to minimize the transfer of thermal energy from our system to the surroundings and vice versa.)*

4. What could cause the difference in the change in temperature of the tap water when using different metals of the same mass? *(The main factor for the difference in the changes in temperatures is the metals’ different specific heats.)*

5. Why is it helpful to know the specific heat of a material? *(Specific heats indicate the sensitivity of materials to temperature changes. Also, since specific heats are always the same for a particular material, they can be used to identify unknown substances.)*
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Recognize and develop testable questions that:
    - Require the changing of one variable at a time.
    - Can be answered with a science investigation or observational study.
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test—changing only one variable at a time makes comparisons valid
  - Explain the investigative process by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials.
    - Describing it so that it can be easily repeated by a fellow scientist

- **Gather Data**
  - Use Tools and the SI (metric) system to accurately measure:
    - Temperature
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Bunsen burner
    - Thermometer
    - Scale
  - Uses the appropriate format to record data:
    - Table
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
  - Assess the conclusion by:
    - Comparing results to hypothesis
    - Extrapolating results beyond the investigation

- **Communication in Science**
  - Report results using:
    - Peer presentation
Written report
Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- **Name the data table**: select a descriptive title or name for the data table.
- **Name each of the columns in the data table**: Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Concept: Thermochemistry

Overview: You will work with a partner to identify the meanings of vocabulary words.

Directions:

1. As you complete the Explore activities for "Thermochemistry," use the Take Notes function of Techbook and the Interactive Glossary to make a list of the glossary terms and their definitions.

2. Work with a partner to highlight other unfamiliar words in the Explore section. Work with your teacher and your partner to find the meanings of the unfamiliar words.

What parts of the Techbook are you using? ________________________________

Who are you working with?

the whole class   a group    one other person    nobody

What will you have when you finish? ________________________________

Glossary Words:

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
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</thead>
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</table>
Name _____________________________
Date _____________________________

English Language Proficiency Activity

Words that you want the teacher or a work partner to help you with:

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
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Hands-On Lab
Enthalpy of Neutralization

Timing: One 90-minute class session

Objective(s):
Students will measure the change in enthalpy during a neutralization reaction between HCl and NaOH. They will use their data to calculate the heat of neutralization for this reaction.

Safety Precautions:
Students should use caution when working with the chemicals in this lab. Hydrochloric acid and sodium hydroxide are corrosive to skin, eyes, and other tissue. Students will be working with 1.0 M solutions, higher concentrations than usual. These concentrations are necessary for a sufficient change in temperature. Alternatively, you may choose to use double the volume of 0.5 M solutions. Excess acid and base must be disposed of carefully. Students should never eat or drink anything in the lab. Students should wear closed-toed shoes, eye protection, gloves, and aprons.

Materials:
For teacher demonstration
- 50 mL of each solution: 1.0 M HCl and 1.0 M NaOH
- wash bottle containing distilled water
- plastic or foam cup with lid
- 400 mL beaker
- thermometer or temperature probe with probeware interface and software
- two 50 mL graduated cylinders or one 50 mL pipette and one 50 mL graduated cylinder
- clock or stopwatch
- paper towels
- gloves, goggles, and lab apron

Per student group
- slightly more than 100 mL of each solution: 1.0 M HCl and 1.0 M NaOH
- wash bottle containing distilled water
- two plastic or foam cups and one lid
- 400 mL beaker
- (optional) additional insulating materials to be available to students on request
- thermometer or temperature probe with probeware interface and software
- two 50 mL graduated cylinders or one 50 mL pipette and one 50 mL graduated cylinder
- paper towels
- clock or stopwatch
- gloves, goggles, and lab apron for each student
Teacher Preparation:
- Prepare or obtain the following solutions:
  1.0 M NaOH (about 102 mL per student group, plus 50 mL for teacher demonstration)
  1.0 M HCl (about 102 mL per student group, plus 50 mL for teacher demonstration)
- If preferred for safety reasons, you may choose to use double the volume of 0.50 M solutions of
  the acid and base. In this case, make sure the plastic or foam cups are large enough for the total
  volume (200 mL reaction mixture, so cups should be at least 300 mL).
- Obtain the MSDS sheets for HCl and NaOH and have them available for students in class.
- Use a sharp knife to make an X in each cup’s lid for the insertion of thermometers or temperature
  probes. If you do not have time to do this, have students make holes in their own cup lids using a
  sharp pencil.
- If you are using probeware, take time to become familiar with the use of temperature probes and
  with any computer software being used. Be prepared to instruct students in the use of probeware.
- Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to
the investigational methods being used in the Hands-On Lab, it is recommended that the Directed
Inquiry approach be used to provide scaffolding that will ensure student safety and support the success
of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory
techniques and methods to be used in the activity. A discussion of each step in the investigative
process will also be included. In some cases, students may then be asked to create a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure
to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry
activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or
manipulate variables of their own choosing. It may be necessary to provide additional materials and
supplies for students using Guided Inquiry. It will also be important to set clear limits on students’
activities to ensure their safety and the relevance of their inquiry experience to the content you are
teaching.

Directed Inquiry

Model for the students the following procedure, explaining the steps as you go.
1. Measure exactly 50.0 mL of HCl in a graduated cylinder. Leave it in the graduated cylinder.
2. Use a pipette or a different graduated cylinder to measure 50.0 mL of NaOH and place it in the
   plastic or foam cup. Place the cup in a 400 mL beaker for stability.
3. Wait three minutes, then measure and record the temperature of each solution. Use distilled water to
   rinse off the thermometer or temperature probe between measurements. Use a paper towel to dry the
   thermometer or temperature probe completely before reuse.
4. Ask students to predict whether the reaction of HCl and NaOH will be exothermic or endothermic.
   Have students write their predictions down.
5. Quickly and carefully pour the HCl solution into the NaOH solution. Put the lid on immediately, and insert the thermometer or temperature probe.
6. Monitor the temperature of the reaction mixture for the next two or three minutes while gently swirling the beaker containing the cup. Record the highest temperature.
7. Ask students how effective they thought the calorimeter was. Invite suggestions on how to reduce heat loss.

For example, students may want to use a doubled plastic or foam cup rather than a single cup.
8. Invite suggestions as to what else might be improved in the procedure.

For example:
- Students may want to measure the heat capacity of their calorimeter by adding 50 mL hot water to 50 mL room temperature water in the calorimeter, and recording the initial and final temperatures. They can calculate the expected final temperature of the water mixture and compare it with the experimental final temperature to calculate heat lost to the calorimeter.
- Also, students should repeat the procedure twice, cleaning and drying the plastic or foam cup before the second time. Students can use the average of their data for their final calculations.
- If the NaOH and HCl were at different temperatures, students may point out that it would be better if both were at the same temperature. For example, the HCl could be heated or cooled by placing the graduated cylinder in a beaker of warm or cool water.

Guided Inquiry

Students can develop their own plans for collecting data, based on their knowledge of the procedure modeled above and materials available. Ask the students some guiding questions to help them focus their inquiry:

- What else could you do to prevent heat loss to the surroundings?
- How could you determine the heat capacity of your calorimeter?
- How could you use the heat capacity of your calorimeter to obtain more accurate results?
- How can you use the data from this procedure to calculate the heat of reaction? (Remind students that heat of reaction is the change in enthalpy per mole.)
- What is the benefit of repeating the procedure more than once?
- Why is it best that both the NaOH and the HCl solutions be at the same temperature?

Remind students that they should begin their activity by choosing a testable question.

Sample questions: What is the heat of reaction for the neutralization of HCl and NaOH? How can I measure the heat of neutralization as accurately as possible? How does the concentration of the two reactants affect my calculation of the heat of reaction?

Warn students that the solutions must be handled carefully. Neutralized reaction mixtures can be disposed of in the sink, but unused acid and base must be disposed of by the teacher. Remind students to prepare a data table to record their data.
Analysis and Conclusions

1. Write the balanced equation for the neutralization reaction.
   \[ \text{HCl} + \text{NaOH} \rightarrow \text{H}_2\text{O} + \text{NaCl} \]

2. Do you think this is an exothermic or endothermic reaction? Justify your answer.
   The reaction is exothermic. Sample explanation: The neutralization reaction produced heat, which means the heat was lost from the system.

3. Calculate the change in enthalpy that occurred during the neutralization reaction. If you performed the reaction more than once, calculate the average of your two measurements.
   Student calculations will vary, depending on whether or not they determined heat lost to the calorimeter. However, values may be somewhere around –2500 J.

4. Calculate the change in enthalpy per mole for this reaction.
   This reaction involved 0.05 mol of each reactant. To obtain the change in enthalpy per mole, students will divide their value by 0.05. Sample Response
   \[
   \frac{-2500 \text{ J}}{0.05 \text{ mol}} = \frac{x \text{ J}}{1 \text{ mol}}
   \]
   \[
   x \text{ J} = -50,000 \text{ J}
   \]

5. The accepted molar enthalpy of neutralization for this reaction is -57.1 kJ per mole. Calculate the percent error of your experimental value.
   Sample Response: My value was –50 kJ per mole. My percent error is
   \[
   \text{percent error} = \frac{\text{experimental value} - \text{theoretical value}}{\text{theoretical value}} \times 100
   \]
   \[
   \text{percent error} = \frac{50 \text{ kJ/mol} - 57.1 \text{ kJ/mol}}{57.1 \text{ kJ/mol}} \times 100 = 12\%
   \]
   Note that percent error has no negative or positive sign.

6. Suggest reasons why your value differed from the accepted value. Explain what could be done differently next time to reduce your experimental error.
   Sample Response: I think we lost heat to the environment. It would work better if we could insulate our calorimeter more. We could use two lids on top. Also, the HCl and NaOH were at slightly different temperatures. Next time we could heat or cool the HCl so they are at the same temperature.

   Note: If students did not calculate the heat lost to their calorimeter, they should include heat lost to the calorimeter here as a source of error.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that
    - asks a question about a specific science concept or process.
  - Recognize and develop testable questions that
    - specify a cause-effect relationship,
    - require the changing of one variable at a time, and
    - can be answered with a science investigation or observational study.
  - Develop predictions/hypotheses that
    - state what may happen in an investigation based on prior knowledge or experience (prediction), and
    - state the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis).

- **Design Investigations**
  - Design and conduct investigations using
    - fair test - changing only one variable at a time makes comparisons valid,
    - independent variable - the one variable the investigator chooses to change,
    - dependent variables - what changes as a result of, or in response to, the change in the independent variable, and
    - multiple trials - repeated tests with the same variables to check for variability of the results.
  - Explain the investigative processes by
    - describing the logical sequence that was used to conduct the investigation,
    - properly citing all equipment and materials,
    - describing it so that it can be easily repeated by a fellow scientist.
  - Practice lab safety by
    - following lab safety procedures,
    - recognizing safety equipment and materials and knowing their proper use, and
    - incorporating laboratory safety practices into the investigation design.

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure
    - volume
    - temperature
  - Choose appropriate tools to conduct an investigation
    - glassware (beakers, flasks, watch glass)
    - thermometer
    - graduated cylinder
    - other laboratory equipment
  - Use the appropriate format to record data
    - table
    - writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns using
    - analysis of data collected during an investigation.
• **Evaluate Evidence**  
  o Draw and support a conclusion by  
    ▪ answering the testable question,  
    ▪ examining how investigations can be improved, and  
    ▪ showing the application of the scientific concept or process being investigated.

• **Communication in Science**  
  o Report results using  
    ▪ peer presentation  
    ▪ written report  
    ▪ scientific explanations/arguments  
    ▪ table/graph showing data

• **Analyze Scientific Results**  
  o Participate in critiquing/peer review by  
    ▪ evaluating an investigative design, and  
    ▪ evaluating data for accuracy.
Answer these problems on this sheet.

1. The phase diagram shown is for an unknown substance A.

Use this diagram to help you answer Question 1

a. Label on the diagram where substance A is liquid.

b. Label on the diagram the triple and critical points (T and C).

c. Provide the temperature and pressure at which substance A can exist as all three phases.

d. What phase does substance A exist in at 100 Celsius and 20 atmospheres?

e. What would happen to the phase of substance A at 70 atmospheres if it was cooled from 500 to 300 degrees Celsius?
2. Look at the phase change diagram below.

Use this diagram to help you answer Question 2

a) On the diagram above label the arrows with the correct word(s) chosen from this list:

- melting
- freezing
- vaporization
- condensation
- sublimation
- deposition

b) On the diagram label the critical point.

c) On the diagram, label the point at which the substance exists as all three phases.
3. Use the phase diagram below to help you answer the following questions:

![Phase Diagram](image)

**Use this diagram to help you answer Question 3**

a) On the diagram label the boiling point of this substance at 1 atmosphere (atm) pressure.

b) On the diagram label the melting point of this substance at 1 atmosphere (atm) pressure.

c) Use the information from parts a and b to suggest a name for this substance.

d) Mark the area of the diagram where the solid phase of this substance turns directly into a gas.
Hands-On Lab
Specific Heat of a Metal

Timing: one 90-minute class session

Objective(s):
In this lab, students will determine the specific heat of a metal using calorimetry. Students will collect and analyze data, and then compare their experimental value with the accepted value. They will analyze, evaluate, and critique their results and method to explain any difference between their experimental value and the accepted value. Students will then design an improved calorimeter, and modify their procedure to improve their results. They will use their improved approach to repeat the first experiment, and compare their two sets of results with the accepted value.

Safety Precautions:
Tell students that the use of hot plates and boiling water presents a burn hazard. Remind students to wear goggles, lab aprons, and closed-toed shoes while in the lab. Remind them not to eat or drink anything in the lab (including the experimental materials). Tell students to report any broken glass, and not to try and clean it up without assistance.

Materials:
Per group:
- goggles
- lab apron
- water
- (1) 250 mL beaker
- (1) hot plate
- (1) balance
- (1) metal sample
- data for the accepted specific heat of the metal used in the investigation
- (1) tongs
- (1) large plastic-foam cup (additional cups may be needed for Guided Inquiry)
- (1) thermometer

Teacher Preparation:
To reduce the time in class, you may wish to pre-heat the hot water baths prior to the start of class. If available, have students use actual calorimeters in place of the plastic-foam cups for improved results. Choose the metal sample, and look up the accepted specific heat of that metal. Prepare a copy of the Student Investigation Sheet for each student.
**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Provide students with the following procedure. Read through it and discuss each step with the class. If necessary, model any steps that students are having trouble understanding. Have students conduct the investigation.

1. Prepare a hot water bath by placing about 150 mL of water in the 250 mL beaker. Set the beaker on the hot plate, and turn the hot plate temperature to high. You may perform this step before students arrive for lab.
2. Measure the mass of the metal sample. Use tongs to place it carefully into the beaker of water on the hot plate.
3. Measure the mass of a plastic-foam cup, which acts as the calorimeter during this investigation.
4. Use the graduated cylinder to add about 60 mL of room temperature water to the cup, and measure the mass of the cup and water.
5. When the hot water bath is near 90°C, reduce the heat setting to medium to prevent boiling of the water.
6. Use the thermometer to measure the temperature of the water in the calorimeter.
7. Use tongs to carefully remove the metal sample from the hot water bath, and then quickly place the metal into the calorimeter.
8. Gently swirl the water in the calorimeter. Check the temperature of the water in the calorimeter every 20 seconds until the temperature stops increasing. Record the highest temperature reached.
9. Use the thermometer to measure the temperature in the hot water bath.
Guided Inquiry

Have students perform calculations to determine the specific heat of the metal before continuing on to the Guided Inquiry section of the investigation. Provide the accepted specific heat of the metal, and have students compare their experimental value with the accepted value. Direct students to analyze and evaluate their results and the method they used to explain any differences. Based on this analysis and evaluation, students can develop their own improved plans for collecting data. Ask the students some guiding questions to help them focus their inquiry:

- **Analyze your results and method:** How did you calculate specific heat? What were the parts of the system being measured? How did you prevent heat entering or leaving the system?
- **Evaluate your results and method:** How accurate were your results? How effective was your procedure? Identify sources of error. Which of these sources of error do you think had the greatest effect on your results?
- **How can you prevent or reduce the impact of these sources of error?** For example, what improvements to materials or procedure might help?

Tell students that they are reenacting the role of lab technicians who are tasked with getting better results from their calorimetric determination of the specific heat of a metal. Students must design and plan improvements in equipment, procedures, or both to address key sources of error they identified in the original experiment. They will need to submit their plan to you for approval before they begin collecting data. Their plan should include the suggested changes to equipment and procedures, the problem each change is designed to address, a step-by-step procedure, and a data collection table. After you have approved a group’s plan, instruct the group to use its plan to begin collecting data.

Some likely improvements that students might suggest include:

- reduce thermal energy lost by better insulating the calorimeter, such as nesting the calorimeter in a second cup and covering the calorimeter with an inverted cup or piece of plastic foam
- correct the amount of energy absorbed by the water by determining the amount of energy absorbed by the calorimeter and thermometer to raise the temperature by 1°C
- eliminate hot water transferred on the surface of the metal by heating the metal sample in a test tube in the hot water bath
- reduce errors in reading the temperatures by using electronic temperature probes
Sample data tables:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass of metal (g)</th>
<th>Mass of cup (g)</th>
<th>Mass of Water and cup (g)</th>
<th>Initial Temperature of Water (°C)</th>
<th>Initial Temperature of metal sample (°C)</th>
<th>Initial Temperature of Water and Metal (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elapsed Time (s)</th>
<th>Temperature of Water in Calorimeter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td></td>
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</tr>
<tr>
<td>220</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td></td>
</tr>
</tbody>
</table>

**Analysis and Conclusions:**

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Apply the first and second laws of thermodynamics to explain the energy changes in this
experiment.

Thermal energy flows from the hot water to the metal sample, and then from the metal sample to the water in the calorimeter. This transfer illustrates the second law of thermodynamics because the energy flows from the higher-temperature substance to the lower-temperature substance. In the calorimeter, the energy absorbed by the water is the same amount of energy lost by the metal. Energy is conserved, which illustrates the first law of thermodynamics.

2. Show how you used your data to calculate the experimental value of the specific heat of the metal.

   *Answers will vary based on student data.*

3. Calculate the percent error between your value and the accepted value of the specific heat.

   *Answers will vary based on student data.*

\[
\% \text{ error} = \frac{\text{experimental} - \text{accepted}}{\text{accepted}} \times 100\%
\]

4. Analyze your results and method:
   (a) How did you calculate specific heat?
      *Sample Response:* I measured the starting temperature of the metal (the same as the hot water). I measured the starting temperature of the water in the calorimeter. I measured the final temperature of the water in the calorimeter. I assumed that all the heat from the metal was transferred to the water. Then I used the equation
      \[q_{\text{metal}} = q_{\text{water}} = c_m \Delta t \text{ for the metal} = c_w \Delta t \text{ for the water}\]
      I solved the equation to find \( c \) for the metal.

   (b) What were the parts of the system being measured? Were these the only parts of the system?
      The metal and the water in the calorimeter were the parts of the system being measured. But the cup and the air probably were part of the system also. Heat was probably lost to the cup and the air.

   (c) How did you prevent heat entering or leaving the system?
      *Sample Response:* We used plastic-foam cups to insulate the system, but it wasn’t good enough. So we doubled up two cups, and covered the top of the calorimeter with another cup.

5. Evaluate your results and method:
   (a) How accurate were your results?
      *Sample Response:* For example, our first results were not very accurate, but after we fixed the materials and procedure we got much closer to the accepted value.

   (b) How effective was your procedure?
      *Sample Response:* For example, the first procedure we used was not very effective, but the second procedure worked better. It wasn’t perfect, though. To get ideal results you probably need high-tech insulating material.

6. Critique your results and method:
(a) If your value was different from the accepted value, explain why.

**Sample Response:** Our value was lower than the accepted value. I think this happened because we lost heat to the air when we moved the metal into the calorimeter. I think we lost heat to the plastic-foam cup and to the thermometer also. Hot water on the surface of the metal was transferred into the calorimeter.

(b) List the changes you made to try to correct the errors you identified.

**Sample Response:** We put the hot water bath much closer to the calorimeter and moved the metal into the calorimeter as fast as we could. We doubled up the plastic-foam cups, and covered the top of the calorimeter to prevent heat being lost.

(c) List any further changes that might improve the procedure even more.

**Sample Response:** We could heat the metal by putting it in a sand bath instead of a water bath so it stays dry. We could collect data on the heat capacity of the thermometer and the plastic-foam cup so we know how much energy these materials absorb.
• Inquiry and Nature of Science Skills in this Lab:

• Design Investigations
  o Explain the investigative processes by:
    ▪ Describing the logical sequence that was used to conduct the investigation
    ▪ Properly citing all equipment and materials
    ▪ Describing it so that it can be easily repeated by a fellow scientist
  o Practice lab safety by:
    ▪ Following lab safety procedures
    ▪ Recognizing safety equipment and materials and knowing their proper use
    ▪ Incorporating laboratory safety practices into the investigation design

• Gather Data
  o Use tools and the SI (metric) system to accurately measure:
    ▪ Volume
    ▪ Mass
    ▪ Temperature
  o Choose appropriate tools to conduct an investigation:
    ▪ Thermometer
    ▪ Balance
    ▪ Graduated cylinder
    ▪ Hot plates
  o Use the appropriate format to record data:
    ▪ Table

• Interpret Data
  o Identify and interpret patterns using:
    ▪ Analysis of data collected during an investigation

• Evaluate Evidence
  o Draw and support a conclusion by:
    ▪ Examining how investigations can be improved
    ▪ Formulating scientific explanations/arguments

• Communication in Science
  o Report results using:
    ▪ Written report
    ▪ Scientific explanations/arguments
    ▪ Table/graph showing data

• Analyze Scientific Results
  o Participate in critiquing/peer review by:
    ▪ Evaluating an investigative design
    ▪ Evaluating data for accuracy
Scientific Endeavor

- Characteristics of Science:
  - Scientists are curious about wanting to know how things work.
  - An important part of science is the critical review and analysis of any idea or conclusion.
  - A law is a description of a specific relationship under given conditions in the natural world.
Hands-On Lab
Stearic Acid Heating Curve

Timing: One 90-minute class session

Objective(s):
Students will conduct an experiment in order to generate a heating curve for stearic acid and use it to determine stearic acid’s melting point.

Safety Precautions:
Instruct students not to try to remove the thermometer from stearic acid that has solidified around the thermometer since this could cause the thermometer to break. Remind students to follow all general lab safety rules, to wear closed-toe shoes, and not to eat or drink anything in the lab. Students should never leave the lab area unattended with chemicals sitting out. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for disposal of stearic acid samples at the conclusion of the lab. Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

Materials:
Per pair of students:
- large test tube 30×200mm
- rubber stopper with hole to fit test tube
- thermometer
- stearic acid
- beaker, 250 mL
- hotplate, or Bunsen burner with ring and wire gauze
- ring stand
- clamp
- timer
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- Prepare a copy of the Student Investigation Sheet for each student.
- Prepare a copy of the procedure (shown below) for each pair of students or display it for the entire class to reference.
- If possible, prepare test tubes with stearic acid in advance for students. To prepare each tube, weigh approximately 25 g solid stearic acid and transfer to a clean 30×200 mm test tube. This will provide about 30 mL of liquid when the stearic acid has melted.
- Place tubes into a warm water bath (above 70°C) and heat until the solid stearic acid melts completely. Into each tube insert a rubber stopper containing a thermometer. Be sure that the thermometer bulb is completely immersed in the liquefied stearic acid. Allow these to cool to room temperature.
- Once a set of test tubes has been prepared, they can be reused over and over again as long as they do not become contaminated with water during the lab procedure.
- Discard contaminated samples in organic waste. Do not discard stearic acid down the sink since it is not soluble in water and will clog the drain.
- The melting point of stearic acid is 69.3 °C. Provide this information to students only after they have determined the melting point experimentally.

Procedure

Set out materials at each student station. Prepare a complete set up of the experiment at the front desk or demonstration table so that students can refer to it as they prepare their own set up. Instruct students to follow the directions below and to record their observations as they carry out the heating procedure. As students work, circulate around the room to observe their progress. You may want to ask students: *What is happening at the molecular level at different times during the heating process?*

1. To set up the apparatus, clamp the ring onto the ring stand so that the ring is positioned about an inch above the top of the Bunsen burner. Place the wire gauze on the ring.

2. Prepare a water bath by adding about 150 mL water to the beaker and placing it on top of the wire gauze on the ring. Position the Bunsen burner underneath the beaker.
3. Insert the test tube containing the solid stearic acid and thermometer/rubber stopper into the water bath and secure it onto the ring stand with the clamp. Be sure that the entire column of stearic acid in the test tube lies below the surface of the water bath. If it is too high, lower the test tube.

4. Light the Bunsen burner to give a blue flame and begin heating the water bath. If you are using a hotplate, turn it to a medium-low setting.

5. Start a timer and record the temperature of the stearic acid every 10 seconds. Record observations of stearic acid as it heats. Continue recording as you observe the solid melting into a liquid.

6. Continue recording data and observations for several minutes after the sample has completely liquefied.

7. Turn off the Bunsen burner or hotplate and allow the setup to cool before dismantling it.

8. Do not to try to remove either the thermometer or stopper from the tube, but return the test tube containing solid stearic acid with its rubber stopper and thermometer to your teacher when the experiment is finished.

9. Graph the data showing temperature on the y-axis and time on the x-axis. Use the graph to determine the melting point of stearic acid.

10. When you have finished, answer the analysis and conclusion questions.

Sample student graph:
Analysis and Conclusions

1. According to your data, what is the melting point of stearic acid? How does this compare with the known melting point of stearic acid, and what are some reasons for any differences?

Sample answer: According to our data, the melting point of stearic acid is 65°C. This is slightly lower than the known melting point of 69.3°C. If our sample was even slightly contaminated with water or something else, our sample would not be pure stearic acid and this could lower the melting point we determined from our heating curve.

2. What did you notice about the pattern of change in the heating curve? Why were there distinctly different sections of the curve?

Sample answer: The curve had three distinct parts. At the lower temperatures, there was a definite rise in temperature with time. At 65°C, the temperature reached a plateau where it flattened out. Once all of the stearic acid had liquefied, the temperature began rising again. These different regions correspond to changes occurring at the molecular level. In the first part of the curve, heat caused the molecules to vibrate faster in the solid state. This increased motion of molecules could be observed as increasing temperature. In the second part of the curve, heat caused the molecules to break intermolecular forces of attraction so that a change from solid to liquid could occur. This absorption of heat did not involve a temperature change because the heat went into breaking the forces of attraction rather than increasing the motion of the molecules. In the third part of the curve, the phase change was over and heat being absorbed was used to move the molecules at an even faster rate, which we could observe as continually increasing temperature.

3. How did the pattern of change in the heating curve allow you to determine the melting point of your sample? What happens at the molecular level in the sample that corresponds to the changes in its temperature at the melting point?

Sample answer: We could determine the melting point by finding the temperature at which there was a shift from increasing temperature to constant temperature over time. This shift to constant temperature indicates that the sample is undergoing a phase transition. The sample continues to absorb heat, but instead of using the heat to increase the kinetic energy of the molecules, which makes them move faster, the heat is used to break intermolecular forces of attraction, such as hydrogen bonds, ionic attractions, van der Waals attractions, and dipole-dipole interactions. Absorption of heat for this purpose does not show up as a change in temperature. So it is at the temperature where a plateau is reached that we can say that the sample began to change from solid to liquid. This is defined as the melting point of the sample.

4. What would a cooling curve for stearic acid look like? How do you know?

Sample answer: A cooling curve for stearic acid would look like the mirror image of its heating curve. This is because the same processes would occur in reverse. We would see the temperature decrease over time as the liquid stearic acid cooled. Eventually, it would reach its freezing point, when the temperature would level off for a period of time while the sample froze, or changed to the solid state. Once it was completely frozen, or completely solidified, the temperature would then begin dropping again. The temperature at the freezing point would be the same as the temperature at the melting point.
In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct investigations using
    - fair test - changing only one variable at a time makes comparisons valid
    - independent variable - the one variable the investigator chooses to change
    - dependent variables - what changes as a result of, or in response to, the change in the independent variable
  - Practice lab safety by:
    - following lab safety procedures
    - recognizing safety equipment and materials and knowing their proper use
    - incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure
    - temperature
    - time
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass)
    - Bunsen burner
    - Thermometer
    - Clock/stopwatch
  - Use the appropriate format to record data:
    - Table
    - Graph

- **Interpret Data**
  - Identify and interpret patterns using
    - trends in data
    - graphed data points
    - analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by
    - using data to determine the cause-effect relationship observed in the investigation
    - reporting trends and patterns in the data
    - formulating scientific explanations/arguments

- **Scientific Investigation**
  - Scientific Data and Outcomes:
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    - Comparisons of data are not accurate when some of the conditions are not kept the same.
Exploration Teacher Guide: Thermochemistry

Overview

The study of heat transfer is called thermochemistry. In this Exploration, students calculate the specific heat capacity of substances using a calorimeter.

Student Learning Objectives

- Observe the structure, function, and working of a calorimeter.
- Calculate the specific heat of the selected substance from initial and final temperature of the substance and the water in the calorimeter.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students select a metal for which they want to calculate the specific heat capacity using the Select Metal dropdown list. The mass of the metal and the mass of water can be selected using the Select Mass of Metal and Select Mass of Water dropdown lists. Students can use the Drop Metal button to drop the metal into the calorimeter and observe the final temperature achieved by the metal and the water in the calorimeter.

Students now use the Proceed button to calculate the specific heat of the selected metal. A popup with the initial and final temperatures of the metal and water appears. Students calculate the specific heat capacity of the selected metal and click on any one of the three answer buttons to validate their answer. The Continue button can be used to return to the Exploration.

Students may use the Reset button to restart the Exploration with another metal.

Using the Tracker tab, students can track the values of mass of the metal, mass of the water, difference in temperature of the metal and water, heat capacity of the calorimeter, and specific heat capacity of the metal.

Answers to Questions in Student Worksheet

1. Explain the term thermochemistry.

   Answer: Thermochemistry is the study of the heat and energy transferred during chemical reactions and physical transformations. It is also used to study the enthalpy and entropy of a system.
2. Explain how specific heat relates to amount of energy needed to change temperature of equal amounts of different substances.

**Answer:** Specific heat is the amount of heat energy, in joules, required to raise the temperature of 1 g of substance by 1°C. Different substances need different amounts of energy to raise the temperature of 1 g of the substance by 1°C. This is based on the chemical and physical properties of substances. Thus, different substances have different specific heats.

3. Explain what a bomb calorimeter is. Also comment on its uses.

**Answer:** A bomb calorimeter is a calorimeter used for measuring the specific heat of a substance and the heat of combustion of a reaction. It is also used to measure the calorie content of foods.

4. Write the formula used to calculate the specific heat of a metal.

**Answer:** The formula used to calculate the specific heat of a metal is

\[
\frac{M_m \times \Delta T_m \times C_{pm}}{} = \frac{M_w \times \Delta T_w \times C_{pw}}{} + \frac{\Delta T_w \times \text{Heat capacity of the calorimeter}}{}
\]

Where, 
- \( M_m \) is the mass of the metal,
- \( \Delta T_m \) is the difference in temperature of the metal,
- \( C_{pm} \) is the specific heat capacity of the metal,
- \( M_w \) is the mass of water,
- \( \Delta T_w \) is the difference in temperature of water,
- \( C_{pw} \) is the specific heat capacity of water.

5. Calculate the amount of heat required to raise the temperature of 1 g of water by 1°C.

**Answer:** The specific heat capacity of water is 4.18 J/g°C. This means that 4.18 J of energy is required to raise the temperature of 1 g of water by 1°C.

6. Use this Exploration to calculate the specific heat of aluminum.

**Answer:** The students may use an aluminum block of 10 g or 15 g to calculate the specific heat of aluminum. They may use 50 g or 100 g of water. The initial temperature of aluminum and water is provided. The final temperature can be obtained from the Exploration. Students will then use the formula

\[
M_m \times \Delta T_m \times C_{pm} = \frac{M_w \times \Delta T_w \times C_{pw}}{} + \frac{\Delta T_w \times \text{Heat capacity of the calorimeter}}{}
\]

to calculate the specific heat of aluminum.
7. Compare the specific heats of copper and iron. Which of these metals requires more energy to raise the temperature of 10 grams of the metal?

**Answer:** The specific heat of copper is 0.385 J/g°C. The specific heat of iron is 0.450 J/g°C. This means that iron requires more energy to raise the temperature of 10 grams of the metal.

8. Use this Exploration to calculate the specific heat of 10g of copper using 50g of water.

**Answer:** The specific heat of 10g of copper using 50g of water is 0.386 J/g°C.

9. Use this Exploration to calculate the specific heat of 15g of aluminum using 100g of water.

**Answer:** The specific heat of 15g of aluminum using 100g of water is 0.885 J/g°C.

10. The specific heat of 15g of a metal was found to be 0.444 J/g°C. The mass of water used was 50g. Calculate the heat capacity of the calorimeter. Also, identify the metal.

**Answer:** The students will use the formula $M_m \times \Delta T_m \times C_{pm} = ( M_w \times \Delta T_w \times C_{pw} ) + ( \Delta T_w \times \text{Heat capacity of the calorimeter} )$ to calculate the specific heat capacity of the calorimeter which is 1.32 J/g°C. The specific heat of the metal used is very close to the specific heat of iron. Therefore, the metal used here is iron.
Overview

In this Exploration, students will investigate the cycling of water and carbon, within one sphere of the Earth (e.g., within the biosphere) and from one sphere to another (e.g. from the atmosphere to the lithosphere). They will examine the components and processes involved in the cycle.

Student Learning Objectives

- Understand that matter cycles and energy flows in cycles within and between Earth's different spheres.
- Investigate the cycling of water and carbon through different spheres of Earth.
- Examine how water changes from one state to the other as it cycles from one sphere to the other.
- Examine how carbon changes from one compound to the other as it cycles from one sphere to the other.
- Analyze the importance of all the processes through which water and carbon cycle within and between Earth's spheres.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion. Note that some questions may require knowledge of additional Earth science concepts. These questions are better used for discussion than for assessment.

Using this Exploration

Students can use the radio button options to explore either the water cycle or the carbon cycle.

Students can examine how water or carbon cycles within and between Earth’s spheres: atmosphere, biosphere, lithosphere, and oceans. They can select a sphere from the Select Sphere (from) section and another sphere from the Select Sphere (to) section. They may select the same sphere in the two sections to investigate how water or carbon cycles within the selected sphere. After the sphere selection, students can use the Trace button to examine how water or carbon, cycles from one selected sphere to the other. Arrows and labels on the cross section along with feedback text, explains the movement.

Students can use the Reset button to undo the current tracing of water or carbon through the selected spheres and select another pair of spheres.

The Tracker tab records information about the cycling of water and carbon that has been in examined in the Explore tab. By default, the information that is displayed here is for the cycle selected in the Explore tab. However, students can use the Select Cycle dropdown list to view the recorded information for the other cycle. The information indicates water and carbon are lost.
and gained through various processes in the different spheres, as they cycle within and between different spheres.

**Answers to the Questions in the Student Worksheet**

1. Identify and describe six processes that act in the water cycle to move water from one place to another, or to convert it from one state of matter to another.

**Answer:** The following processes are a part of the water cycle:
- Evaporation is a process through which liquid water is converted to water vapor.
- Transpiration is a process through which liquid water from plants evaporates.
- Condensation is a process through which water vapor is converted to tiny droplets of liquid water.
- Precipitation is a process through which droplets of liquid water, or crystals of solid water (ice) fall under gravity from the atmosphere.
- Percolation is a process through which water from the surface of the ground seeps into the rocks and soil below.
- Volcanic eruptions also contribute to the water cycle by transporting water within magma from deep underground to the surface, where it escapes as water vapor into the atmosphere.

2. Identify and describe four processes that are a part of the carbon cycle, and act to move carbon from one place to another or transform it from one form into another.

**Answer:** The following processes are a part of carbon cycle:
- Dissolution is a process by which calcium carbonate dissolves at great depths in the ocean and releases carbonate ions.
- Combustion is a process through which burning of carbon-bearing solids releases carbon compounds like carbon dioxide (CO₂) and methane (CH₄) into the atmosphere.
- Respiration is a process through which oxygen is transported (by breathing) from the atmosphere into the cells of organism and carbon dioxide is transferred from the cells of the organism into the atmosphere. This process is reversed in plants.
- Volcanic eruptions, and metamorphism of carbonates, in comparatively small amounts, also contribute to the carbon cycle.

3. Describe the role of photosynthesis in the water and carbon cycle.

**Answer:** During photosynthesis, plants consume carbon dioxide and water and convert them into carbohydrates. Plants absorb water into their structure, is the carbon in the carbohydrates and the water in the plants are passed on to the herbivores and then to the carnivores in the food chain.
4. By what set of processes could water and carbon can be moved from the atmosphere to deep underground, and then back to the atmosphere again?

**Answer:** Water could fall onto the ground, percolate through the soil and rock, and then be subducted into the mantle. It could then rise up in a magma body and erupt as water vapor at a volcano. Carbon could move from the atmosphere into a plant via photosynthesis. The plant could then be buried and become part of rock or sediment that is subducted into the mantle. It could then move up toward the surface in a body of magma and then be erupted as carbon dioxide gas at a volcano.

5. Carbon dioxide (CO₂) and methane (CH₄) are both greenhouse gases. Greenhouse gases allow sunlight to pass through to Earth’s surface, but keep heat escaping from the atmosphere. Describe the two natural processes that add greenhouses gases to the atmosphere and two natural processes that remove greenhouse gases from the atmosphere.

**Answer:**
- Animal respiration, decomposition, combustion of carbon-bearing solids like coal and oil, volcanic eruptions, metamorphism of carbon-rich rocks, and deposition of calcium carbonate all add greenhouse gases to the atmosphere.
- Photosynthesis, weathering, and dissolution into water all remove greenhouses gases from the atmosphere.

6. Greenhouse gases are important in keeping Earth’s surface warm enough for life. However, a rapid increase in greenhouse gases in the atmosphere can lead to global warming, which can be harmful to many species. Why is an understanding of the carbon cycle important for environmental scientists and engineers who are trying to prevent rapid global warming? Based on your understanding of the carbon cycle, what are two ways to try to prevent global warming?

**Answer:** A scientist or engineer who understands the carbon cycle understands how greenhouse gases like carbon dioxide and methane get into the atmosphere and how they can be removed from the atmosphere. This allows scientists and engineers to come up with solutions to either decrease the amount of greenhouse gases going into the atmosphere, or increase the amount being removed from the atmosphere. Two possible solutions are decreasing combustion of carbon-bearing materials so less carbon dioxide goes into the atmosphere, and planting more trees and plants so that more carbon dioxide is removed from the atmosphere.

7. Some people refer to water as a renewable natural resource and others warn that it can be non-renewable. Use your understanding of the water cycle to defend both arguments.

**Answer:** Renewable: Water is renewable in that it is constantly being cycled from one reservoir to another. If we use water to irrigate farms, for example, it is not used up forever. It percolates
into the soil, is taken up by plants, and then evaporates back into the atmosphere, or is eaten by animals. If water gets polluted, it gets purified when it evaporates back into the air. Non-renewable: Although water is continuously cycling, it takes time for it to cycle and it may not always return to the same place. In certain areas, water can be use faster than it is replenished by the water cycle.

8. The carbon cycle can be described using chemical reactions. When carbonate rocks like limestone and silicate rocks like sandstone are metamorphosed, the components may react with each other:

\[
\text{CaCO}_3 + \text{SiO}_2 \rightarrow \text{CaSiO}_3 + ?
\]

What is the missing product in this chemical equation? What does the equation tell you about the role of metamorphism in the carbon cycle?

**Answer:** The missing component is CO\(_2\) (carbon dioxide). The equation shows that carbon dioxide is released during this metamorphic reaction.

9. Do you think the total amount of carbon and of water in the Earth system is increasing, is decreasing, or stays the same? Explain your answer.

**Answer:** The total amount of carbon and of water in the Earth system stays about the same. As it is removed from one sphere of the Earth it is added to another sphere. Student might note that some water and carbon are lost to space, which is true, and some enters the Earth via comets and meteorites. Because this exploration does not focus on the section of the geosphere below the lithosphere, the student might also note that water and carbon enter the other spheres via volcanism, while some is returned via subduction.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:

- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Decomposition

Timing: This lab will take place in 20–30 minute intervals over several weeks of class time.

Objective(s):
Students will study how different materials break down in soil.

Safety Precautions:
- Students should use caution and wear gloves when grating food products. If you are concerned about students cutting themselves, you may grate the products for students immediately prior to class; do not wait too long between grating the products and beginning the lab, lest the food begin to decompose before it is added to the soil.

Materials:
Per small group:
- 1-gallon clear container
- 1 gallon of potting soil
- 1 organic product (e.g., apple, potato, tomato, carrot, lettuce, dried leaves, newspaper, straw)
- Grater
- 1-cup measuring cup
- Large spoon for mixing
- Watering can and water
- Earthworms, 8 per group (optional)

Teacher Preparation:
- It is best for students to begin this lab in the first session of this lesson. This gives the various materials time to decompose.
- Have group members mix the contents of their container every two to three days. Care should be taken not to harm earthworms if used.
- If you choose to introduce earthworms into the lab, you may wish to have several groups of students work with the same product but add earthworms to only some of the containers; this will allow students to observe how earthworms affect the rate at which a product decomposes.
- If using earthworms, make sure treatment of these organisms is humane.
- Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative
process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Introduce the lab at the beginning of the lesson. Explain to students that they will be investigating the process of composting using different organic substances. The class will be divided into small groups of 3–4 students. Each group will receive one food product (e.g., potato, apple, carrot, lettuce, tomato) or one dried item that is not food but is still organic (e.g., newspaper, dried leaves, straw). The number of products can be adjusted to match the number of groups in the room; if there are more products than groups, each group may choose its product, but each group should observe the decomposition of only one product. At least one group should have a recalcitrant form of organic carbon (i.e., dried leaves, straw) that will not break down quickly.

This lab will be conducted over the course of a week or longer. Each group will make initial observations of its chosen product on the first day. Groups should mix the soil in their containers every two to three days and make additional observations regarding how their respective products change as they break down over time. If it is possible, provide each group with eight earthworms. This will speed up the breakdown of the material. Students should be careful when mixing the soil not to harm the earthworms.

Each group should form a hypothesis about what will happen to its product over the course of the lab; their observations during the lab will then confirm or contradict their hypothesis. If students struggle to make their hypotheses, help them by posing the following question: What will have happened to my food after one week (or more) in the soil? Urge students to be as specific as possible, and ensure that they will be able to confirm their answers simply by making observations with their unaided eyes. (For example, if students say “My food will rot,” ask them what “rot” means—what observations will confirm that their food is rotting? A stronger hypothesis would be “My food will turn brown and break into tiny pieces.”)

Each group should begin by filling a 1-gallon container three-fourths of the way with soil. (Containers should be clear so that students have views of their decomposing products from various angles.) To speed up the decomposition process, each group should grate or otherwise break into pieces its product immediately prior to placing it in the soil.

- If working with a non-leafy food product, students should grate one cup of the material.
- If working with dried leaves, students should crumble the leaves into different-sized pieces.
• If working with lettuce or newspaper, students should rip the leaves or pages into different-sized pieces.
• If working with straw, students should break the straw into different-sized pieces.

Each group should sprinkle the soil in its container with water. (Do not saturate the soil—simply make the surface moist.) Use the spoon to mix the grated or ripped product gently into the soil. If using earthworms, students should gently place the earthworms onto the soil and cover them with additional soil.

Students should record their observations of their product in the soil on the first day of the lab and every few days thereafter. Every few days students should also add water to the soil in their containers and mix it gently. Students should note the quality of the soil, the state of the product, and the state of the earthworms (if using them). They may record their observations in a table such as the following:

<table>
<thead>
<tr>
<th>Product: Earthworm (y/n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
</tr>
<tr>
<td>------</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

**Guided Inquiry**
Groups performing the Guided Inquiry version of this lab rather than the Directed Inquiry version should select two different products to observe in separate containers. (Thus, for Guided Inquiry each group will require two containers and two gallons of soil.) Prior to beginning the lab, students should
hypothesize which product will decompose more rapidly and explain why they think so. Their
observations throughout the course of the lab will then confirm or disprove their hypothesis.

Alternatively, students may change a different variable rather than the type of product. For example,
they may compare how apples decompose in a container with earthworms to how apples decompose in
a container without earthworms. Or they may place one container under a heat lamp and compare the
effect of temperature on decomposition. (Do not use earthworms with a heat lamp.) Or they may double
the amount of water they sprinkle on one container, or close one container and leave the other
container open.

Students can develop their own plans for collecting data, based on their knowledge of the procedure
and materials used. Ask the students some guiding questions to help them focus their inquiry:

- What will happen to the product as it sits in the soil over time?
- What would happen to the product if it were not grated?
- What will be the effect of the earthworms on the product over time?
- What factors increased or inhibited the rate of decomposition?

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the
following questions, or assigning them as homework:

1. How did your group’s product change from the first day of the lab to the last day of the lab?
   On the first day of observation, students should note that the material in question is finely grated or torn
   and mixed throughout the soil. By day two, products that contain relatively large amounts of water (e.g.,
   apples, tomatoes, lettuce) should begin to disintegrate in the soil. Products with less water (e.g.,
   carrots, potatoes, newspaper) should begin to break apart, appear smaller, and show some signs of
   breaking down. The recalcitrant products (e.g., leaves, straw) should remain relatively unchanged. By
day five, many of the food products should have disappeared almost entirely, while the other food
products as well as the newspaper should be heavily broken down. The recalcitrant products should not
have changed. If earthworms are included in the lab, the rate of decomposition for most products
should increase.

2. Compare your results with those of your classmates. Which material decomposed the most and
   which material decomposed the least?
   Students should note that some products (e.g., apple, tomato, lettuce) decompose rather rapidly.
   Students who observed straw and leaves should note that the material decomposed very little.
   Students who observed potatoes, carrots, or newspaper should note that their products fall in the
   middle between the rapidly decomposing and the minimally decomposing products.

3. What happens to the decomposed material?
   The material breaks down into its constituent components (e.g., sugars, minerals, nutrients—students
do not need to know the specific names of components). If worms were included in the lab, students
should note that some of the materials were eaten by the worms and expelled as castings.
4. How do your observations relate to the cycling of matter and energy in nature? 
As materials break down, their constituents are returned to the soil. Other plants and organisms can use these materials as fuel to perform their life functions. The process of decomposition observed in this lab is an essential form of natural recycling that continues to move matter and energy around the planet.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct field studies using:
    - Survey - collects multiple data points at one point in time
    - Observational Study - compares changes in data points over time
  - Practice lab safety by:
    - Following lab safety procedures
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Examining how investigations can be improved
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
    - Written report
    - Table/graph showing data
- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Analyzing scientific explanations

- Patterns and Systems
  - Patterns and Change:
    - Things that change may do so in steady, repetitive or irregular ways.
    - Many patterns in nature occur in cycles.
    - Cycles may be short, such as the second hand of a clock, or long such as the cycle of a year.
  - Systems:
    - No matter how substances within a closed system interact with one another, or how they combine or break apart, the total mass of the system remains the same.
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.

- Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
  - Scientific Data and Outcomes:
    - Some data can be collected in a short period of time (e.g. motion of a rolling ball) and some data takes much longer (e.g. the growth of a tree).
    - Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
    - It is important in science to keep honest, clear, and accurate records.

- Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.

- Engineering and Technology
  - Societal Issues:
    - Scientific discoveries have benefitted people in many ways
Hands-On Activity
Modeling a Negative Feedback Loop

Objective:
Students will work in pairs to model a negative feedback loop by regulating the water level in a leaky cup. They will then relate the model to the human body’s regulation of water level.

Estimated time to complete: 15 minutes

Materials:
For each student:
- bowl
- clear plastic cup, small
- cup (any material), large
- permanent marker
- scissors
- tap water

Procedure:
Have students carefully use the scissors to poke a small hole in the bottom of the small plastic cup. Then have students mark a line on the side of that same cup to represent a minimum water level of about two centimeters. Instruct students to fill the larger cup with water. Tell students to hold the small plastic cup over the bowl during the activity to catch the water that leaks out.

To model the negative feedback loop, have students pour water from the large cup into the small cup so that the water level is above the marked line. Tell students they must make sure to keep the water level at or above this line at all times, but they should also not let the cup overflow.

Have students maintain their systems for about two minutes. Then have pairs discuss the following questions:

- How was this model an example of a negative feedback loop? (If the water level went outside a certain range, I reacted by changing the water level so it came back within range.)
- What were the parts of the control system in this loop (the sensor, processor, and actuator)? (Sample answer: My eyes acted as the sensors, my brain was the processor, and my hand holding the large cup of water was the actuator. My nervous system linked all of these parts together.)
- How is this model similar to the way the human body maintains its water level? (The body must also make sure the water level is within a certain range. Like the leaky cup, humans lose water from their bodies. The body uses a control system to bring the water level back within range.)
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Kinesthetic (balance, position)
- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Extrapolating results beyond the investigation
    - Showing the application of the scientific concept or process being investigated
- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating a conclusion
- **Patterns and Systems**
  - Systems:
    - A system, such as the human body, is composed of subsystems.
    - Some systems (such as heating or cooling systems) have feedback mechanisms that serve to keep changes within specified limits.
    - Physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.
Hands-On Lab
Modelling the Carbon Cycle

Timing: one 90-minute class session

Objective(s):
Students will develop a quantitative model of the carbon cycle illustrating how carbon moves through each of Earth’s spheres. Students will work in groups to calculate estimated carbon dioxide emissions for a fictional country and then determine the necessary number of hectares of trees needed to make that country carbon neutral. Their fictional country will be designed with existing data from different countries from around the world. Students will also design a representational model that details the amounts of carbon emissions and the amount of forested hectares needed by their country. Students will finally create a map of their fictional country to illustrate the cycle of carbon through the geosphere, atmosphere, hydrosphere, and biosphere as well as the relationship between each of Earth’s systems. Students will present their models to their peers for analysis.

Safety Precautions:
Remind students to follow all general lab safety rules.

Materials:
Per group:
- copy of the data tables
- carbon challenge sheet
- calculator
- graph paper or computer graphing program
- poster paper
- writing tools
Teacher Preparation:
- Gather materials in advance of students performing the lab.
- If possible, have students review what they have learned about the carbon cycle before beginning the lab.

Introduction

2. Using the image, remind students how carbon moves through the different spheres on Earth. Provide them with the terms: biosphere, atmosphere, geosphere, and hydrosphere. If they are not familiar with these terms after their work in the concept, share the following definitions in relation to the carbon cycle:
   - The **biosphere** holds carbon in living things, such as in trees and plants which absorb CO₂ during the process of photosynthesis, and in the animals that eat the plants.
   - The **atmosphere** holds carbon in a bonded form with oxygen. The air we breathe contains carbon dioxide.
   - The **geosphere** holds elemental carbon from the original formation of rock, as well as carbon from ancient living things that have become compressed into soil and rock over time. The water cycle can release carbon from the geosphere, as can weathering of rock.
   - The **hydrosphere** contains dissolved carbon dioxide. The world’s oceans can both hold carbon and return it to the geosphere as it sinks to the bottom and, under certain conditions, release carbon back into the atmosphere.
3. Explain to students that they will have an opportunity to model this carbon cycle in the Carbon Challenge.
4. Have students form lab groups and collect the necessary materials.

Carbon Challenge
Using the data provided, your group should design a country that has a neutral carbon status. You will choose the basic statistics of your country considering the climate (different climates have different types of trees), economy (first-world economies produce greater CO₂ emissions), and population (CO₂ emissions are on a per-capita basis). Once you determine the parameters of your fictional country, give it a name and then determine measurements of population and CO₂ emissions that are similar to an existing country’s data as supplied in Data Table 1. Using that data, you will calculate the number of hectares of forest coverage you will need to give your new country a carbon neutral status. Once you have made the calculations, you will design a representational map of your new country that shows the amounts of carbon moving through the different spheres of Earth. You will then present your model to the class.
Procedure

1. Explain to students that the data in the tables are not exact, as factors such as population and CO₂ emissions are constantly changing. However, the data is reliable in comparison to the other figures in the table.

2. Explain to students that they will be challenged to design a carbon neutral country. They will choose the basic statistics of their country considering the climate (different climates have different types of trees), economy (first-world economies produce greater CO₂ emissions), and population (CO₂ emissions are on a per-capita basis).

3. Explain to students that they will then create a table and record the statistics of their new country basing them on similar data from existing countries as listed in Data Table 1. They should determine population and CO₂ emissions of their country and should give this country a name.

4. Students should calculate the total CO₂ sequestered by different types of forests, as shown in Data Table 2.

5. Once they have decided on the parameters of their new country, students should use some simple calculations to find the following:
   - total carbon dioxide emissions for their country
   - the number of tons of carbon the ocean can absorb (30% of total)
   - how many hectares of trees the new country will need (total minus what the ocean can absorb)

   Remind students that different climates have trees that sequester different amounts of CO₂. They should record these calculations in a table similar to the Sample Data Table provided below.

6. Finally, students should create a representational map of their new country that shows, in metric tons, where carbon is moving through the different spheres. They should show how much CO₂ is absorbed by the biosphere and the hydrosphere, and how much is released into the atmosphere. The map should also show (with arrows) how carbon is released and stored in the geosphere.

7. Once the groups have finished the representational map of their carbon neutral country, they should present their country’s statistics and map to the class.

8. As an extension, students can calculate the same information for the real countries provided and discover if their current forest coverage is sufficient for the CO₂ emissions those countries are producing.
### Data Table 1: Country Statistics

<table>
<thead>
<tr>
<th>Country</th>
<th>Forest coverage in hectares</th>
<th>Forest type</th>
<th>2010 CO₂ tons produced per year/person</th>
<th>Population in millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>300 million</td>
<td>temperate</td>
<td>17.6 tons</td>
<td>322</td>
</tr>
<tr>
<td>Brazil</td>
<td>477 million</td>
<td>tropical</td>
<td>2.2</td>
<td>200</td>
</tr>
<tr>
<td>Germany</td>
<td>11 million</td>
<td>temperate</td>
<td>9.1</td>
<td>82.6</td>
</tr>
<tr>
<td>China</td>
<td>157 million</td>
<td>temperate</td>
<td>6.2</td>
<td>1390</td>
</tr>
<tr>
<td>India</td>
<td>64 million</td>
<td>tropical/temperate</td>
<td>1.7</td>
<td>1260</td>
</tr>
<tr>
<td>Cayman Islands</td>
<td>12,000</td>
<td>tropical</td>
<td>10.6</td>
<td>0.058</td>
</tr>
<tr>
<td>Canada</td>
<td>400 million</td>
<td>boreal forest</td>
<td>14.7</td>
<td>35</td>
</tr>
<tr>
<td>Madagascar</td>
<td>13 million</td>
<td>tropical</td>
<td>0.1</td>
<td>22</td>
</tr>
<tr>
<td>Kuwait</td>
<td>6,000</td>
<td>tropical</td>
<td>31.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Finland</td>
<td>23 million</td>
<td>boreal</td>
<td>11.5</td>
<td>5.4</td>
</tr>
</tbody>
</table>

### Data Table 2: CO₂ Sequestering Measurements

<table>
<thead>
<tr>
<th>Type of Tree</th>
<th>Density trees/hectare</th>
<th>CO₂ sequestered/tree per hectare/year (metric tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>tropical</td>
<td>650</td>
<td>22.6 kg/year/tree</td>
</tr>
<tr>
<td>temperate</td>
<td>350</td>
<td>13 kg/year/tree</td>
</tr>
<tr>
<td>boreal</td>
<td>283</td>
<td>1 kg/year/tree</td>
</tr>
</tbody>
</table>

### Sample Data Table: Country with Neutral Carbon Status

<table>
<thead>
<tr>
<th>Country Name</th>
<th>Type of forest</th>
<th>Population</th>
<th>Total CO₂ produced tons/year</th>
<th>Ocean absorption 30% in tons/year</th>
<th>Total hectares needed for carbon neutral status</th>
</tr>
</thead>
</table>


Analysis and Conclusions

1. How well was your final map able to model the cycle of carbon through the different spheres? Explain.
   The model was only able to show the relationship between human contributions to the carbon cycle and the forest part of the biosphere, but it was not able calculate the contribution of other plants and living things. It was also difficult to assign a value to amounts of carbon in the geosphere. This demonstrates that calculating amounts is very complicated and involves a great number of different factors.

2. Do you think your fictional country could exist? Explain why or why not.
   Depending on the population of the country and how much CO₂ it was producing, it may have been unrealistic to have that much forest coverage for the area. Real countries have cut forests down to provide area for agriculture and living space. The fictional countries may have been designed for small populations and large tropical forests to provide a lower carbon emission, but realistically many countries with tropical climates have very large populations.

3. The model had some limitations. In what areas was the model too simplistic?
   The model did not address the causes of CO₂ emissions and, therefore, reducing the CO₂ in the atmosphere might have been achieved through means other than forest coverage. Reduction of fossil fuel use may be one solution. In addition, the model did not explain the consequences to habitat from carbon absorption by the oceans.

4. What did you learn about the real-world importance of trees while designing this model?
   Trees do an incredible and reliable job of sequestering carbon from our atmosphere. The model demonstrated that global deforestation will have a serious consequence if our CO₂ emissions continue to increase.

5. In which sphere is it most difficult to anticipate the amount of carbon? Why?
   The geosphere is more difficult to measure. It is unknown how much carbon is in the geosphere or how much of it will be released in the future. Weathering rates are dependent on acidity levels of rainwater. Acid rain can speed up the release of carbon to the hydrosphere. The length of time it takes to sequester carbon in rock formations is too long for use in making good estimations. The conditions required for the process may not be ideal in the future.
In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Make or use models that:
    - Simulate the real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing.

- **Gather Data**
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- **Evaluate Evidence**
  - Assessing the conclusion by:
    - Identifying alternative explanations
  - Communication in Science
    - Peer presentation

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Identifying alternative explanations

- **Engineering and Technology**
  - Uses of Technology
    - Technology extends the ability of people to make positive and/or negative changes in the world.
  - Engineering Design
    - Even a good design may fail even though steps are taken ahead of time to reduce the likelihood of failure.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Overview
In this Exploration, students examine structural layers of Earth’s interior and their properties. Students also identify the mineral composition of layers.

Student Learning Objectives
- Examine the five structural layers of Earth’s interior.
- Identify the mineral composition for each of the five layers.

Student Worksheet
The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration
In this Exploration, students use models to investigate the five structural layers of Earth’s interior.

In the Explore tab, students use the slider to select one of the five layers from the model of Earth’s interior. Upon selection, information about the selected layer is displayed. Students use the Proceed button to view an animation of the selected layer. More information about the selected layer is displayed. Students click the Proceed button for the next section, in which they identify the mineral composition of the selected layer. Students use the radio button options to select the correct mineral composition. They use the Submit button to validate their selections.

Students can use the Select Another Layer button at any time during the Exploration to restart and select another layer.

The Tracker tab records the options that the student selects in the Explore tab after the student correctly identifies the mineral composition of each selected layer.

Answers to Questions in Student Worksheet
1. Identify the composition of oceanic and continental crustal rocks. In a model of Earth’s interior, where would these rocks appear?

   Answer: Oceanic crust is composed primarily of dark-colored mafic rocks, rich in iron and magnesium. Continental crust is composed primarily of light-colored felsic rocks rich in silica and feldspars. Crustal rocks would appear in the part of a model that represents Earth’s lithosphere: Earth’s crust is the upper part of the lithosphere.
2. Describe how Earth’s crust responds to the addition and removal of mass.

**Answer:** The height of the surface of Earth’s crust varies in response to addition and removal of materials from Earth’s interior due to processes such as earthquakes, volcanoes, and tsunamis.

3. Name the transition zone from the mantle to the core-mantle boundary and explain its significance.

**Answer:** The transition zone from the mantle to the core-mantle boundary is called the “D layer.” It is the zone where the lower mantle (which consists of silicate rock) meets Earth’s liquid-iron outer core.

4. How does a geologist know the thickness of different layers inside Earth? How might a model of Earth’s interior show the relative thickness of each layer?

**Answer:** Geologists know the thickness of different layers inside Earth by studying the behavior of seismic waves (earthquake waves) as they move through Earth. P waves can travel through both solid and liquid layers, while S waves can travel through solid layers only. The time it takes for the P and S waves to pass through layers indicates the thickness of the layers. A model of Earth’s interior should show each layer in order from lithosphere to inner core. Layers that are thicker in actuality should be thicker in the model. For example, the average thickness of the lithosphere is approximately 100 km, and the asthenosphere is between 500 and 600 km thick; therefore, in a model of Earth’s interior, the part that represents the asthenosphere should be five to six times as thick as the part that represents the lithosphere.

5. Explain the term *rheology* and name the rheological layers of Earth. How might a model of Earth’s interior distinguish among Earth’s rheological layers and compositional layers?

**Answer:** *Rheology* is the study of how matter deforms and flows, either in a solid or a liquid state. The names of the rheological layers of Earth are the lithosphere, asthenosphere, mesosphere, liquid outer core, and solid inner core. In contrast, Earth has three compositional layers: the crust, mantle, and core. The rheological and compositional layers overlap. A model might use solid lines to distinguish among Earth’s compositional layers and use colors to distinguish among Earth’s rheological layers. For example, by shading the crust and the upper mantle red, a model could show where the lithosphere begins and ends.

6. Explain the similarities between Earth’s mineral composition and that of meteorites.

**Answer:** Extraterrestrial rocks that have landed on the surface of Earth are called meteorites. Meteorites are composed mainly of pyroxenes, olivines, chondrites, iron-nickel metals, coesite, and stishovite, which are very similar to the overall composition of Earth.
7. In this Exploration, select asthenosphere and examine how the tectonic plates below the continents are subducted. List two names given to the boundaries where subduction occurs and explain what these boundaries characterize.

**Answer:** Subduction occurs at convergent boundaries of oceanic and continental crust. They also are called destructive boundaries because oceanic crust is destroyed during subduction, and continental crust is shortened as it is folded and faulted.

8. Explain how geologists know that the mesosphere is more rigid than the overlying asthenosphere.

**Answer:** Geologists know the mesosphere is more rigid than the overlying asthenosphere by the way seismic waves behave when they move through it. When seismic waves move from the asthenosphere to the mesosphere, they speed up. This is evidence that the mesosphere is denser and less fluid.

9. List one characteristic feature of the asthenosphere and one of the mesosphere. How might a model of Earth’s interior represent these features?

**Answer:** The hot rocks of the asthenosphere rise, while cooler rocks sink to produce convection currents. A model might use arrows to show the directions in which differently colored rocks move. (For example, hotter rocks could be shaded red and labeled with an upward-pointing arrow; cooler rocks could be shaded blue and labeled with a downward-pointing arrow.) The mesosphere causes hot spot volcanism when narrow plumes of hot mantle move from deep within the mesosphere to the surface. To represent such a plume, a model might include a narrow column, shaded dark red, extending from the part that represents the mesosphere to the surface.

10. Describe the main features of Earth’s core. How might a model of Earth’s interior represent these features?

**Answer:** Earth’s core is divided into an outer core and an inner core. The outer core is liquid, and the inner core is solid. The temperature of the outer core ranges from about 3500°C at the outer portion to about 6000°C at the inner portion. The inner core temperature is about 6000°C, which is hotter than the surface of the sun. A model might include labels that identify the temperature and state of matter (that is, solid or liquid) of each layer.

11. Explain what creates the magnetic field surrounding Earth’s outer core.

**Answer:** Earth’s outer core is composed of liquid metal. Convection currents of liquid metal in the outer core are thought to create Earth’s magnetic field.
Hands-On Lab
Model Earth’s Interior

Timing: one 90-minute class session

Objective(s):
Students will model Earth's interior, including its structural and compositional layers.

Safety Precautions:
Offer safety reminders to students relevant to the modeling materials they are working with. For example, remind students to use caution with sharp edges if working with cutting tools. Students should not eat or drink anything in the lab.

Materials:
Per group:
- Assortment of modeling materials and tools (e.g., clay, modeling dough, foam, sponge, paints, yarn, aluminum foil, craft knives, paintbrushes, glue)
- Metric ruler
- Thicknesses of Earth's Interior Layers chart

Teacher Preparation:
Before the lab, collect and sort modeling materials so that each group will have access to a sufficient supply of a variety of materials. Groups will not be creating a 3-dimensional model of the entire globe or even half the globe; instead, they will simply show a thin cross-section of the planet. To conserve materials, models may be nearly 2-dimensional, and they should stop at Earth's center—for the purposes of this lab, students may assume that the “bottom” half of Earth’s interior mirrors the “top” half. If materials are extremely limited, groups may simply create 2-dimensional posters. You may wish to create your own model prior to class so that you can better anticipate obstacles.

Guided Inquiry will likely require more time to complete than Directed Inquiry. If class time is limited, you may need to assign students parts of the lab to complete for homework.

Make a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Divide students into small groups. Explain that the goal of the lab is to create scale models of Earth’s interior layers. The models must demonstrate how the process of thermal convection cycles material throughout the asthenosphere, forms new oceanic crust (lithosphere), and pulls under old oceanic crust. Give students a few minutes to discuss with their groups what it means for a model to be “to scale,” then discuss responses as a class. If students have difficulty with the concept, ask them to imagine making a scale model of themselves as a 1-m tall clay statue. Ask students questions to guide their thinking, such as:

- What would it mean for your 1-m statue to be “to scale”? (My body parts would be in the right proportion; my head wouldn’t be too big or small compared to my body.)
- How would you figure out how big you needed to make each part of the statue in order for it to be to scale? (I would first measure the size of each of my body parts—its length or thickness. Then I would compare these measurements to the size of my whole body by making each body part a fraction or proportion of my whole body. I would then divide the statue into the same proportions using much smaller measurements based on a total height of 1 meter.)
- How could you follow this process to create a scale model of Earth’s interior? (I would divide the radius of the model by the radius of Earth to figure out what fraction each layer needs to be reduced by.)

Next, give students a chart containing the thickness of each structural and compositional layer:

**Thickneses of Earth’s Interior Layers**

<table>
<thead>
<tr>
<th>Structural Layer</th>
<th>Approximate Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithosphere</td>
<td>15–300 km (from Earth’s surface to top of asthenosphere; average thickness of 80 km)</td>
</tr>
<tr>
<td>Asthenosphere</td>
<td>250 km (from bottom of lithosphere to top of mesosphere)</td>
</tr>
<tr>
<td>Mesosphere</td>
<td>2550 km (from bottom of asthenosphere to top of outer core)</td>
</tr>
<tr>
<td>Outer Core</td>
<td>2200 km (from bottom of mesosphere to top of inner core)</td>
</tr>
<tr>
<td>Inner Core</td>
<td>1250 km (radius—i.e., from bottom of outer core to Earth’s center)</td>
</tr>
</tbody>
</table>
Compositional Layer | Approximate Thickness
--- | ---
Oceanic Crust | 5–10 km (from Earth’s surface to top of mantle)
Continental Crust | 30–100 km (from Earth’s surface to top of mantle)
Mantle | 2900 km (from bottom of crust to top of outer core)
Core | 3450 km (radius—i.e., from bottom of mantle to Earth’s center)

Instruct each group to use these data to determine a scale for their models. For example, if every centimeter represents 10 km, then they would need to create a model of Earth with a radius of approximately 630 cm; this is probably too large—a scale of 0.5 cm = 1 km is more reasonable. Again, emphasize that groups will not be creating a 3-dimensional model of the entire globe or even half the globe—they should show only a cross-section of the planet. Groups may also create several models to allow them to use multiple scales—i.e., because the difference in thickness between Earth’s top layers and its middle and bottom layers is so great, one model could focus on the crust, while a second model could focus on the mantle and core.

However groups make their models, they should use different materials, colors, or textures to represent each layer, and include labels or a key that identifies each layer and describes its main features. Challenge groups to represent Earth’s structural as well as compositional layers in their models; however, you may wish to modify the lab to allow struggling students to represent only one set of layers.

Groups should begin by sketching their models on paper, testing their scale, and labeling the thickness of each layer. They should also draw the circular thermal convection currents that bring hotter material from the bottom of the asthenosphere up to the top of the asthenosphere. They should include a break in the oceanic crust (lithosphere) at a mid-oceanic ridge, where rising hotter material from the asthenosphere would be pushed out to form new crust. Groups should also include a thinner portion of the lithosphere being subducted, or pulled, under the thicker continental crust (also lithosphere) and returning to the asthenosphere at both edges of the oceanic crust (lithosphere.) Check students’ work and correct any errors in scaling. Remind students that the lithosphere has two separate thicknesses for the thinner oceanic crust and thicker continental crust. Then, point out the available modeling materials and instruct groups to determine which materials should represent which layer of Earth. Each group should provide a rationale for its choices based on the actual composition of each layer. (For example, more brittle materials could be used for the lithosphere and more fluid materials could be used for the asthenosphere.) If students struggle, ask them the following guiding questions:

- How will you build the model so that the layers come out in the proper order and thicknesses?
- How will you build the model so that it provides a clear view of Earth’s interior structures?
- How can your model represent processes in Earth’s interior, like convection? (Note that simple arrows may be necessary to model dynamic processes such as convection.)
- How will you label your model to give viewers information?
Finally, have groups build their models. When they are finished, groups should display their models for the class, ask for feedback, and make any necessary adjustments to improve the accuracy of the models. Have group members discuss the following "wrap-up" questions:

- What were some of the challenges in creating a scale model? (sample answers: figuring out the correct thicknesses of each layer; accurately representing the crustal thickness relative to the much thicker mantle and core)
- What are the models good at representing? (sample answers: the relative thicknesses of the layers; some of the properties of each layer)
- What are some of the limitations of the models? (sample answers: It is difficult to show movement in the model, so it was difficult to represent convection cells and lithospheric plate motion.)

Guided Inquiry

Students can develop their own plans for using the materials to create a scale model of the interior structures of Earth. Students should also conduct their own research to determine the thickness of each of Earth’s structural and composition layers. Ask the students some guiding questions to help them focus their inquiry:

- How will you use the information you learn about the thickness of each of Earth layers to create an accurate scale model?
- How can you use different materials to represent some of the characteristics of Earth’s interior layers?
- How will you construct your model to provide a view of Earth’s interior?
- How will you show thermal convection currents? Will you draw on the model, add clay arrows, or use some other method?

Groups should begin by sketching their models on paper, testing their scale, and labeling the thickness of each layer. Check their work and correct any errors in scaling. Then, point out the available modeling materials and instruct groups to determine which materials should represent which layer of Earth. Each group should provide a rationale for its choices based on the actual composition of each layer. Once you have approved a group’s plan, allow its members to build their model.

When groups have completed their models, they should display them for the class, ask for feedback, and make any necessary adjustments to improve the accuracy of the models. Have group members discuss the following "wrap-up" questions:

- What were some of the challenges in creating a scale model? (sample answers: figuring out the correct thicknesses of each layer; accurately representing the crustal thickness relative to the much thicker mantle and core, representing thermal convection currents, which are a movement rather than a material)
- What are the models good at representing? (sample answers: the relative thicknesses of the layers; some of the properties of each layer)
- What are some of the limitations of the models? (sample answers: It is difficult to show movement in the model, so it was difficult to represent convection cells and lithospheric plate motion.)

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework.

1. How did you figure out the appropriate thickness of each layer in your scale model?
   *Sample response:* I figured out the thickness of each layer as a fraction of Earth’s radius and then applied those same fractions to the radius of the model.

2. Were you able to accurately represent the scales of all the layers? Explain.
   *Sample response:* It was difficult to accurately represent the thickness of the crust because it was only a fraction of a percent. Also, different types of crust have different thickness.

3. What were the challenges of building the model?
   *Sample answers:* remembering to double the thickness of the inner core; adding each layer without deforming the ones beneath; cutting the model to reveal the inside structure without crushing or distorting layers.

4. What difficulties did you have in showing thermal convection currents with the model?
   *Sample answers:* While we created arrows on the model to show movement of hot and cold material in thermal convection currents, or represented the subduction of the oceanic crust or the expansion of material at the mid-oceanic ridge, showing the movement of material was much more difficult than showing its composition and thickness.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Apply mathematical operations and principles to replicate the real thing.
    - Have been revised as new knowledge and information has been obtained
    - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Length/distance/depth
  - Choose appropriate tools to conduct an investigation:
    - Ruler/tape Measure
  - Use senses to observe:
    - Seeing (color, shape, size, texture)
    - Touching (shape, size)
    - Kinesthetic (balance, position)
  - Identify and interpret patterns using:
    - Tables and graphs

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
    - Peer presentation

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Analyzing scientific explanations

- **Patterns and Systems**
  - Patterns and Change:
    - Many patterns in nature contain symmetry.

- **Scientific Endeavor**
- Characteristics of Science:
  - Science is based on factual knowledge.
  - An important part of science is the critical review and analysis of any idea or conclusion.
Hands-On Lab
A Boundary Issue

Timing: one 90-minute class session

Objective(s):
Students will use candy bars to model plate boundaries. Students will then conduct research on actual plate boundaries.

Safety Precautions:
Students should not put anything into their mouths during the lab. Because chocolate can get messy, students may wish to wear lab aprons and gloves, and they should tie back long hair and loose clothing. Students should use caution when working with plastic knives. All candy bars should be returned to the teacher at the end of the lesson.

Materials:
Per group:
- 3 candy bars consisting of a nougat center and a chocolate coating, at or slightly below room temperature
- Vegetable oil (about ¼ cup)
- Smooth plastic sheet (or cutting board)
- Plastic knife
- Paper towels
- Map showing Earth’s major tectonic plates (Earth’s Major Plates)
- Computer with access to Internet

Teacher Preparation:
- In addition to the candy bars for each group, you will need one candy bar for a pre-lab demonstration.
- Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed
Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Introduce this lab after students have completed the sections of Explore in the Core Interactive Text that are related to the first Essential Question: What are the three main types of plate boundaries? Students should be able to identify the three main types of plate boundaries and explain the different ways plates interact along those boundaries.

Divide students into pairs or groups of three. Explain that each group will use candy bars to model each plate boundary. Show students a candy bar that you have cut in half, and point out both the nougat center and the chocolate coating. Give groups a few minutes to discuss how the different layers of the candy bar represent the different layers of Earth that are affected by the movement of tectonic plates. Discuss students’ ideas as a class; guide students to understand that the chocolate is similar to Earth’s lithosphere (i.e., the brittle crust and upper mantle that compose tectonic plates), and the nougat, which “flows” without breaking, is similar to the soft and pliable but still solid asthenosphere upon which the tectonic plates ride.

Next, distribute the materials. Instruct each group to place a thin layer of oil on its board; this will help to prevent the candy bars from sticking to or dragging against the board as students manipulate them.

Model 1
Instruct each group to use a plastic knife to cut its first candy bar cross-wise into two equal-length pieces and place the pieces on the oiled board. Each group should use its pieces to model a convergent boundary. (To do this, students should set the two pieces lengthwise and opposite each other on the board, and then gently push the pieces together, applying compressional stress until the chocolate cracks, the nougat is deformed, and parts of the candy bar are forced upward. See the sample, below.) Group members should also:

- Sketch their observations of the pieces as they are pushed together.
- Explain in their notes how the deformed chocolate and nougat represent what happens at a convergent boundary. (The chocolate—i.e., lithosphere—cracks, which can result in earthquakes, and is forced upward, which can result in mountain-building. Pieces of chocolate are thrust on top of each other and some are folded. These processes also happen to rocks in the lithosphere.)

Explain in their notes how their model does not accurately represent all convergent boundaries. (Sample answer: Where at least one plate consists of oceanic lithosphere, the denser plate subducts beneath the less dense plate. Neither piece of candy bar was dense enough for this to happen in our model. This better models a convergent boundary between two continental plates.)
Model 1: Sample Before-and-After

Using paper towels, groups should wipe their boards, removing any bits of candy bar and applying more oil to ensure a smooth surface. Then, instruct each group to use its second candy bar to model a divergent boundary. (To do this, students should place the bar on the board and gently pull on each end, applying extensional stress until the bar breaks apart, as in the sample below. If the bar is particularly firm, they may use the knife to cut the candy bar partially in half before pulling it apart. Either method will simulate divergence within a plate and the formation of a new divergent boundary.) Group members should also:

- Sketch their observations of the pieces as they are pulled apart.
- Explain in their notes how the deformed chocolate and nougat represent what happens at a divergent boundary. (If the chocolate is not cut before stress is applied, the chocolate layer represents a single tectonic plate breaking apart to form a new divergent boundary. If the chocolate is cut first, it models what happens between two plates that are moving apart. In both cases, the breaking of brittle chocolate resembled the extensional faulting of a plate.)
- Explain in their notes how their model does not accurately represent a divergent boundary. (Sample answer: Where two oceanic plates diverge, magma from the mantle can erupt through the gap, forming new crust as it cools; we were unable to model this process. It is also hard to model normal faulting with a candy bar. In real life, the rocks of the lithosphere would drop down during extension. In this model, they just separated from each other, revealing the “asthenosphere” beneath. If the candy bar broke along several fracture zones, this too is different from what usually happens. In most cases,
extension causes a single major fault zone, not a number of them.)

Model 2: Sample Before-and-After

![Image of candy bar before and after](image_url)

Model 3
Using paper towels, groups should wipe their boards, removing any bits of candy bar and applying more oil to ensure a smooth surface. Then, instruct each group to use its third candy bar to model a transform boundary. (To do this, students should place the bar lengthwise on the board, gripping opposite corners, and gently push, applying shear stress until the bar splits apart, with one half passing the other half. If the bar is particularly firm, they may first use the knife to cut vertically into the long ends of the bar, about 1 cm deep—i.e., if they were to continue cutting, they would divide the bar into two long, thin pieces. Either method will simulate a plate breaking along a new transform boundary. If there are extra candy bars available, students may want to experiment by applying stress cross-wise to see what happens.) Group members should also:

- Sketch their observations of the pieces as they are pushed together and then slide apart.
- Explain in their notes how the deformed chocolate and nougat represent what happens at a transform boundary. *(If we don’t cut the chocolate first, we are modeling what happens as a single tectonic plate begins to break into two along a new transform boundary. As the candy bar breaks apart, the chocolate cracks and pieces of chocolate slide past each other. The same thing happens when a plate breaks apart and two pieces start to slide past each other. In a real plate, the fracturing and faulting of the rocks would cause earthquakes. If we cut the chocolate first and then apply stress, we are modeling what happens along an older transform between two plates. The stress still causes the chocolate (the lithosphere) to break and fault, and the two plates move past)*
• Explain in their notes how their model does not accurately represent a transform boundary. (Sample answer: Our candy bar did not behave like solid brittle rock. Instead, it crumpled into a ball-like mess as we pressed it together—every part was deformed by the stress. Tectonic plates are much thicker and wider than our candy bars, so parts away from the boundary can remain intact, despite the deformation happening along the boundary.)

Model 3: Sample Before-and-After

![Diagram of a before-and-after comparison showing deformation of a block of material.](Image)
Students may wish to organize their notes in a table such as the following:

<table>
<thead>
<tr>
<th>Model</th>
<th>Stress applied</th>
<th>Observations</th>
<th>Limitations of Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Convergent boundary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Divergent boundary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Transform boundary</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discuss groups’ results as a class. Different groups may find different ways to model each boundary (for example, some groups may cut their candy bars completely in half before modeling divergent or transform boundaries); encourage groups to offer each other feedback, and urge each group to explain the limitations of its choices—i.e., how does a particular model not accurately represent what happens at a plate boundary?
Next, present each group with the map Earth's Major Plates, shown below:

Groups should conduct research on the Internet to answer the following questions about specific locations along at least five different plate boundaries. (Students will need to focus on specific locations along each boundary because in most cases more than one type of boundary exists between any two plates.)

- What kind of boundary is it (convergent; divergent; transform), and what kind of lithosphere is on either side (oceanic-oceanic; continental-continental; ocean-continental)?
- What are some landforms or other geologic features at this boundary? How were they formed or shaped by plate movements at the boundary?
Students may wish to organize their notes in a table such as the following:

<table>
<thead>
<tr>
<th>Plates</th>
<th>Exact Location along Boundary</th>
<th>Types of Lithosphere</th>
<th>Type of Boundary</th>
<th>Geologic Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>North American Plate and Eurasian Plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific Plate and North American Plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific Plate and Philippine Plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pacific Plate and Nazca Plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Caribbean Plate and Cocos Plate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>etc.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Guided Inquiry**

Students will use candy bars to model the three different kinds of plate boundaries (e.g., convergent, divergent, and transform). Students can develop their own plans for working with the candy bars and collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- Which parts of Earth’s interior do the chocolate coating and nougat represent?
- What happens to Earth’s lithosphere at each type of boundary? What happens to Earth’s other layers?
- How can you model these boundaries and the processes that occur at these boundaries using candy bars?
- What are the limitations of using candy bars to model plate boundaries—i.e., how does each model not accurately represent what happens at a plate boundary?

This model may instill a misconception; that the asthenosphere also deforms during convergence. Inform the students that while convection in the asthenosphere helps drive plate motion, it isn’t involved to any great extent in deformation itself. Use this as an opportunity to discuss the difficulties of modeling processes in the Earth’s interior.

Discuss groups’ results as a class. Different groups may find different ways to model each boundary; encourage groups to offer each other feedback, and urge each group to explain the
Next, present each group with the map **Earth’s Major Plates**. Groups should conduct research on the Internet to answer the following questions about specific locations along at least five different plate boundaries on the map. (Students will need to focus on a specific location along each boundary because in most cases more than one type of boundary exists between any two plates.)

- What kind of boundary is it, and what kind of lithosphere is on either side?
- What are some landforms or other geologic features at this boundary? How were they formed or shaped by plate movements at the boundary?

In addition, instruct each group to sketch the edge of one of the plates they researched, labeling the plates on the other side and noting the type of boundary at each location along the edge.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Describe how the candy bars represent each tectonic plate boundary (both the boundary type and the type of crust affected).
   *In model 1, the candy bar pieces move together, and the candy was forced upward. This scenario represents two plates of continental lithosphere coming together at convergent boundary, resulting in mountain-building. In model 2, the candy bar was pulled apart until it broke, forming a jagged fissure. This scenario could represent continental crust moving apart at a divergent boundary, resulting in a rift zone; it could also represent oceanic crust moving apart at a divergent boundary, resulting in seafloor spreading. In model 3, the candy bar pieces moved past each other horizontally. This scenario represents lithosphere moving in opposite directions at a transform fault.*

2. How did the candy bar model fail to represent the various plate boundaries and the relationship between the lithosphere and asthenosphere? (It was difficult to model normal faulting with a candy bar. In real life, the rocks of the lithosphere would drop down during extension. In this model, they just separated from each other, revealing the “asthenosphere” beneath. The candy bar did not behave like solid brittle rock. Instead, it crumpled into a ball-like mess as we pressed it together—every part was deformed. Tectonic plates are much thicker and wider than our candy bars, so parts away from the boundary can remain intact, despite the deformation. The model asthenosphere deformed in our model. In the Earth, while convection in the asthenosphere helps drive plate motion, it isn't involved to any great extent in deformation itself.)

**Further Questions**
1. For each of the three plate boundaries, describe one actual, specific feature on Earth that forms at the boundary.
   *Sample answers (be sure that each plate boundary is represented): The Middle America trench forms at a convergent boundary and stretches along Central America from Mexico to Panama.*
The Mid-Atlantic ridge is a divergent spreading center that bisects the length of the Atlantic Ocean. The San Andreas Fault is a transform fault that spans more than 1,000 km along the western edge of California.

2. How does an understanding of plate boundaries help a person understand features on Earth’s surface?
   If we understand how plates interact, we can explain the locations of mountains, volcanoes, earthquakes, trenches, and spreading centers along plate boundaries. This knowledge is also valuable for reconstructing conditions in Earth’s geologic past, especially regarding the formation and breakup of supercontinents, changes in climate conditions, distribution of ocean currents, and evolution of living organisms.

3. How can an understanding of plate boundaries help engineers and city planners?
   Understanding where a city is located relative to a plate boundary helps us understand how the area could be affected by natural phenomena like earthquakes and volcanic eruptions. This is important for engineers and planners designing things like buildings, transportation systems, and other elements of infrastructure.
Inquiry Standards and Nature of Science Standards

• Design Investigations
  o Make or use models that:
    ▪ Simulate a real thing that cannot easily be studied or manipulated
    ▪ Allow the testing of a hypothesis with results that can be extrapolated to the real thing

• Gather Data
  o Use the appropriate format to record data:
    ▪ Table
    ▪ Writing (journal, worksheet, electronic text)

• Communication in Science
  o Report results using:
    ▪ Written report
    ▪ Table/graph showing data

• Patterns and Systems
  o Patterns and Change:
    ▪ Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    ▪ Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
Data/Graph Tool
Teacher's Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Activity
San Andreas Fault Movement

In this activity, students will use the current direction and rate of tectonic plate movement along the San Andreas Fault to calculate how long it will take for Los Angeles to be alongside San Francisco if current plate motion continues.

Materials
Per student:
- scale map of California with the San Andreas Fault, San Francisco, and Los Angeles marked
- ruler
- pencil with eraser

To introduce the activity, review the definitions of the following terms: tectonic plate, fault, and strike-slip (transform) fault. Explain that the San Andreas Fault is a large transform fault at the boundary between two tectonic plates: the Pacific Plate and the North American Plate. Movement along the transform boundary is resulting in the Pacific Plate moving northward, with respect to the North American plate, about 6 cm per year.

Procedure
Distribute a map to each student. Maps should show the San Andreas Fault, and San Francisco and Los Angeles should be clearly identified. Maps should include a scale, as students will need to find the distance along the fault between the two cities to make their calculations. You may locate your own map, or you may use the sample included on the next page.

1. Have students complete the “Key Question” section of their student sheets.
2. Remind students of the given data: the Pacific Plate and the North American Plate. Movement along the transform boundary is resulting in the Pacific Plate moving northward, with respect to the North American plate, about 6 cm per year. Have students think about what additional data they will need to calculate how long it will take for Los Angeles to be side by side with San Francisco if this current plate motion continues. Then, ask students what mathematical operations they will use.
3. Have students complete the “Plan” section of their student sheets. You may wish to approve students’ plans before having them move on to the calculations. A sample procedure follows:
   a. Using the map scale, find the distance, in kilometers, along the fault between the two cities.
   b. Convert kilometers to centimeters using 1 km = 100,000 cm
   c. Divide the total distance in centimeters by 6 cm.
4. Have students complete the “Data,” “Calculate,” “Conclude,” and “Analysis and Conclusions” sections of the student sheet.
5. Have students compare their results with a partner’s prediction. Ask them to discuss possible reasons for any variations between the two predictions.
6. Discuss with students the limitations of the activity. For example, the calculation assumes a constant rate of motion, which is not guaranteed and may be influenced by future earthquakes.
Analysis and Conclusions

1. How long will it take for Los Angeles to be alongside San Francisco if current plate motion continues?
   Sample response: The cities are separated by approximately 60,000,000 cm, so they will be alongside each other in approximately 10,000,000 years.

2. Explain how you arrived at your answer.
   Answers will vary. The sample procedure on the previous page lists an appropriate solution.

3. How might you create a model that supports your answer by showing the effect of plate motion on the future locations of Los Angeles and San Francisco?
   Answers will vary. Students’ models should allow the plates on both sides of the fault to move parallel to each other until the two cities are side by side.
Scale Map of California:

Key

San Andreas Fault line

San Francisco

Los Angeles
Exploration Teacher Guide: Tectonic Plate Interactions

Overview

Continents and ocean floor move as parts of huge slabs of lithosphere known as tectonic plates. The plates converge, diverge, and slide past each other, moving at a rate of few centimeters per year. In this Exploration, students explore the different plate boundaries, different plate interactions, and the geological features formed as a result of each interaction. They also investigate the locations of the different tectonic plate boundaries using a world map.

Student Learning Objectives

- Investigate the different ways in which tectonic plate interact.
- Identify different geologic features formed when these tectonic plates interact.
- Examine the locations of the different tectonic plate boundaries in the world from the world map.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion. Some questions require students to think critically and apply knowledge of other concepts. These questions may be better for discussion than assessment.

Using this Exploration

In the Boundaries tab, students examine a present day world map displaying the convergent, divergent, and transform plate boundaries. The plate names are displayed. Students may use the Interactive Key buttons to control the plate boundaries that are visible on the map.

In the Interactions tab, students use the radio button options in the Select Types of Lithosphere to Interact section to select a pair of interacting plates. Similarly, the students can select the type of plate interaction using the radio button options in the Select Type of Plate Interaction section. Note that when the student selects the options Oceanic, Continental and Divergence, information appears in a pop-up box indicating why this type of an interaction is not possible. Students use the Start button to view an animation and examine what happens when the selected plates interact in the selected way. After observing the animation, students use the Proceed button to identify a feature formed due to this interaction. The feature to be identified is highlighted in the image. Students use the radio button options to identify the feature correctly and then use the Submit button to validate their selection. Feedback corresponding to their response is displayed in a pop-up box. In some cases the students are asked to identify more than one feature.

Students can select the Reset button at any time during the Exploration to examine a different interaction between the same or different plates.
In the Tracker tab, students track the various plates and plate interactions that they have explored. They also track all the geological features and the locations of places in the world where similar plate movements are taking place.

Answers to Questions in the Student Worksheet

1. How are volcanoes and earthquakes related to plate tectonics?

   **Answer:** Volcanoes can form along the boundaries where tectonic plates are converging or diverging, bringing the hot material from the mantle and lower crust up to Earth’s surface. Earthquakes generally occur near all three types of plate boundaries when the rocks along either side of the boundary break and move against each other, and the built up stress between the rocks constituting each plate is released.

2. Scientists examine the composition of the volcanic rocks that erupt from volcanoes. Explain what information about Earth’s interior they can gather from this.

   **Answer:** After eruptions have occurred, scientists study the composition of volcanic rocks to learn more about Earth’s crust and mantle, where the magmas originate. Scientists study the mineralogy, the elemental and isotopic composition of the minerals, and the composition of fluids and gases trapped in the rocks. All of this provides information about where the magma came from and how it formed. This helps us learn more about what the crust and mantle are made of, and how plate tectonics works.

3. Describe the relationship between crust, mantle, lithosphere, asthenosphere, and tectonic plates.

   **Answer:** The Earth can be divided into different layers based on composition and also based on how they behave. The crust and mantle are the two upper compositional layers of the Earth. The crust is composed of less dense minerals than the mantle. The lithosphere and asthenosphere are the two upper mechanical layers of the Earth. The lithosphere is the brittle upper layer, while the asthenosphere is the lower, more plastic and fluid layer. The lithosphere is made of crust and uppermost mantle. The asthenosphere is made of mantle below the lithosphere. The tectonic plates are made of lithosphere.

4. Explain how convection can cause tectonic plates to move.

   **Answer:** The asthenosphere is so hot that the rocks can flow over very long periods of time: hot rocks rise up from below while cool rocks sink. The rock in the asthenosphere is thought to convect, and flow in convection currents, in the same way that ocean water and air in the atmosphere convects. Scientists think that the lithospheric plates ride on top of the fluid, convecting asthenosphere.
5. How can a geologist measure the rate and direction of tectonic plate movement using satellites?

**Answer:** The rate and direction of plate movement can be measured and calculated by using the Global Positioning System (GPS). It is a system of twenty-one satellites arranged in different orbits; so that, from any point of Earth at least four are visible. The GPS receiver on the ground records the signals received from these four satellites to its exact location on the ground. By recording locations of a number of points on the plate and on adjacent plates, and measuring how those locations change over time, geologists can calculate how much movement has occurred between plates.

6. Based on elevation measurements over time, we know that the Himalayas are still rising. At the same time, the Appalachian Mountains in the Eastern US, are getting lower. Explain why this is happening.

**Answer:** The Himalayas are a mountain range located between two plates that are still colliding. This collision caused the initial uplift of the Himalayas, and because it is still happening, the mountains are continuously rising. The Appalachian Mountains, on the other hand, are an ancient mountain range. They formed in a similar manner to the Himalayas, but the collisions that formed them are no longer occurring. They are getting lower over time as a result of erosion.

7. Distinguish between constructive plate margins and destructive plate margins.

**Answer:** Divergent plate boundaries are called constructive plate boundaries because movements of plates away from each other results in the formation of Earth’s crust from the eruption of lava along the boundary. Convergent plate boundaries are called destructive plate boundaries because movement of plates towards each other results in Earth’s lithosphere being destroyed as the plates collide with each other and one plate subducts between the other.

8. Explain the two types of strike-slip faults.

**Answer:** Strike slip fault is a fault in which the major displacement is horizontal and parallel to the strike of the fault plane. Strike slip faults are of two types- sinistral, or left-lateral, and dextral, or right-lateral. Left-lateral faults are strike slip faults in which the far side of the fault moves to the left relative to the near-side. Right-lateral faults are strike-slip faults in which the far side of the fault moves to the right relative to the near-side.

9. Who is best known as the “father of plate tectonics”? Why is he called this?

**Answer:** Alfred Wegener has been acknowledged as the “father of plate tectonics” because he proposed the continental drift hypothesis. Continental drift was the precursor to the modern theory of plate tectonics.
10. Iceland is one of many places that offer scientists a natural laboratory for studying plate tectonics. Explain.

**Answer:** Iceland is formed from the divergence between the North American and Eurasian Plates to produce the mid Atlantic ridge. Iceland is one of only a few portions of this ridge that are exposed on land. Thus, Iceland provides a window into the divergence of oceanic plates and related geological processes.
Hands-On Activity
World Volcanoes Map

Objective:
Students will locate different volcanoes around the world. They will specify the types of eruptions that occurred in each location. As a class, they will discuss the relation between plate tectonic boundaries and volcanic eruption style.

Estimated time to complete: 30 minutes

Materials:
For each student/pair:
- Access to a large, atlas-style map of the world
  - You may want to place the maps on pieces of cardboard or corkboard to cushion them and to prevent students from damaging surfaces with the pushpins.
- 5 differently colored pushpins or small stickers
- 2 index cards

Procedure, Part I:
At the beginning of the lesson, assign each student or student pair (depending on number of students) one of the following historical volcanic eruptions to research:

1. Mount St. Helens
2. Novarupta (1912)
3. Eyjafjallajökull (2010)
4. Mt. Vesuvius
5. Mt. Erebus
6. Tarawera (1886)
7. Kilauea
8. Piton de la Fournaise
9. Mount Fuji
10. Yellowstone Caldera
11. Krakatoa (1883)
12. Mount Fuji
13. Klyuchevskoy Volcano
14. Mount Kilimanjaro
15. Erta Ale
16. Pico Volcano
17. Volcan Villarica
18. Nevado Del Ruiz
19. Anatahan
20. Ascension  
21. Mount Pinatubo

These 21 volcanoes border the Pacific Plate and the Mid-Ocean Ridge. Most are stratovolcanoes, but they include several examples of shield volcanoes. Several show activity in the East African Rift system, and several are related to hotspots. To provide a greater range of locations, consider adding volcanoes in the Aleutian Islands and island systems in the Pacific such as Fiji, Vanuatu, and Tahiti.

For this part of the activity, students will research only the locations of their assigned volcanoes. When students have located their volcanoes, they should mark the location in the world map or atlas using a pushpin or sticker; all pushpins or stickers should be the same color. In part II, students will use differently colored markers to distinguish between types of volcanoes and eruptions.

When all the volcanoes have been marked, discuss as a class whether students notice any patterns in terms of where the eruptions have happened. (For example, students will likely note that many of the volcanoes form a “ring” around the Pacific Ocean—this is often called the Ring of Fire.) Ask students to guess how these patterns might relate to the types of volcanoes that form in these places and the kinds of eruptions that happen there. Record students’ responses on the board so you can discuss them further after students have learned more about these topics in the lesson.

Procedure, Part II
Instruct students to locate their assigned volcano on the world map or atlas and to replace their original pushpin or sticker with a new one that indicates the type of eruption or volcano. Provide the class with a color key such as the following:

- Red = Shield Volcano
- Blue = Stratovolcano
- Green = Fissure Eruption
- Yellow = Caldera Eruption

Emphasize that students should make their best guesses based on the information they learned in the Core Multimedia Reading Path. Students may also need to locate pictures of their volcano in order to determine its profile and summit characteristics (e.g., vent crater, caldera, etc.); they may also need to compare the volcano’s location on the map to the locations of nearby plate boundaries, island arcs, and other geologic features. After replacing their pushpins or stickers, each student should find a partner and explain why he or she made that particular identification. Partners should agree or disagree with each other’s identifications, explaining their own reasons for this choice.

Then, instruct students to continue researching their assigned volcanoes to learn whether their identifications were correct or incorrect. Each student should then write the correct identification on an index card, along with a complete explanation of how that particular eruption happened and which features of volcanism it produced in the surrounding area. Students should then post their index cards on the map or atlas, replacing their pushpin or stick with the correct color if necessary.
**Procedure, Part III**

Working with their partners from Part II, students should hypothesize how their assigned volcanoes might have affected the surrounding region in both constructive and destructive ways. Each partner should create the initial hypothesis for his or her own volcano; partners should then offer feedback on each other’s hypotheses and revise their hypotheses as appropriate.

Then, instruct students to continue researching their assigned volcanoes to learn about the constructive and destructive effects of the eruptions on the surrounding regions. Students should take notes on whether new land or fertile soil was created, as well as whether hazards such as lava flows, pyroclastic flows, lahars, earthquakes, tsunamis, volcanic bombs, and ash falls harmed organisms living nearby. On new index cards, partners should then write paragraphs describing the effects they noted for each eruption, and post their cards alongside their volcanoes on the world map or atlas.
Inquiry and Nature of Science Skills in this Activity:

- Identify Questions
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship

- Interpret Data
  - Identify and interpret patterns using:
    - Trends in data
    - Repeating physical or data patterns
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Extrapolating results beyond the investigation

- Communication in Science
  - Report results using:
    - Table/graph showing data
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Formation of Volcanoes

Overview

A volcano is a naturally occurring opening in Earth’s crust through which lava, a mixture of liquid rock, crystals, and gases, erupts. In this Exploration, students use instruments like the tiltmeter, electronic distance meter, and extensometer to measure slight changes in volcano morphology.

Student Learning Objectives

- Understand how the tiltmeter, electronic distance meter, and extensometer are used to detect impending volcanic eruptions.
- Analyze the changes in volcano morphology using the recorded data.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion. Some questions may require students to apply knowledge gained from other Discovery assets or even from other concepts. These questions are better used for discussion than for assessment.

Using this Exploration

In the Apparatus tab, students select the radio button options to get familiar with the apparatus and the setup used in this Exploration. They learn about the working of the tiltmeter, electronic distance meter, and extensometer to detect impending volcanic eruptions.

In the Explore tab, students select a location from the radio button options in the Select Location section and select the monitoring apparatus from the two radio button options in the Select Monitoring Apparatus section. The displayed cross section changes based on the location selected. Students can use the Record button to view an animation of the changes in the cross section and to update the table with readings recorded by the selected apparatus. After all the readings are recorded in the table, students use the Plot button to examine the graph of distance (in meters) versus time (in days or months) or tilt (in microradians) versus time (in months), depending on the selected apparatus. After examining the graph, students may use the Record button to view the same animation in the cross section and to update another table with readings that would be recorded by the other apparatus. After all readings are recorded in the table, students use the Plot button to examine the graph of the data.

Students may use the Reset button to undo what they have done and record data for another location using another monitoring apparatus. They can also view an animation of formation of volcanoes at subduction zones using the View Formation button.
In the *Location* tab, students examine a present day world map displaying the locations of volcanoes at subduction zones, hotspots, continental rifts, and mid-ocean ridges. They may use the *Interactive Key* buttons to view volcanoes at different locations.

In the *Tracker* tab, the location of volcano formations along with where they are found in the world is displayed. Students use the buttons in the *View* column to examine the formation of the volcanoes at the corresponding locations.

**Answers to Questions in the Student Worksheet**

1. Compare and contrast magma and lava.
   
   **Answer:** Magma and lava are both mixtures of hot liquid rock, crystals, and gas. When this mixture is beneath the Earth’s surface, it is called magma. Above Earth’s surface, this mixture is called lava.

2. Compare and contrast the working of electronic distance meter (EDM) and extensometer.
   
   **Answer:** EDM and extensometer are instruments used to measure change in distance between two benchmarks set near a volcano. An EDM is used to monitor impending volcanic eruptions above sea level while extensometers are used to monitor impending submarine volcanic eruptions. An EDM uses electromagnetic (light) signals while an extensometer uses sound waves to measure distance.

3. Explain how a tiltmeter monitors impending volcanic eruptions.
   
   **Answer:** A tiltmeter is an instrument used by geologists to monitor impending volcanic eruptions. It can be placed at the rim of a caldera, on the flanks of the volcano, or on the crater floor, and is used to measure extremely small changes in the slope angle or “tilt” of the surface. The tilt increase when the magma from the magma chamber pushes overlying rocks up. As the magma moves up toward the ground surface, the slope of adjacent areas usually tilts away from the center of uplift. If the ground surface subsides when the magma moves below or when it erupts, the slope of adjacent areas tilts toward the center of subsidence.

4. What units of measurement are used in the EDM and tiltmeter data? Explain what each unit means.
   
   **Answer:** Tilt is measures in units of microradians. A microradian is $10^{-6}$ radian. A radian is about 57 degrees, so one microradian is about 0.0057 degrees. The EDM and extensometer measurements are in units of meters. One meter is 100 centimeters, or 0.1 kilometers.
5. In general, submarine volcanic eruptions that occur along mid-ocean ridges do not pose much risk to human life. Explain.

**Answer:** Volcanoes formed at mid-ocean ridge do not pose much risk to human life as they erupt under water and are away from civilization. In addition, they are generally effusive, or quiet, rather than explosive eruptions.

6. In this Exploration, tools like the tiltmeter, extensometer, and EDM are used to detect and monitor impending volcanoes. Think about what happens before and during an eruption. What other tools could be used to detect or monitor eruptions.

**Answer:** Seismometers can be used to detect earthquake that occurs as magma moves beneath the surface and as it erupts, and as the volcano collapses. Volcanic gas detectors can be used to detect emissions of gases like sulfur dioxide that may escape before or during an eruption. Satellites can be used to monitor the height of a volcano and also monitor the escape of gases, ash, and lava.

7. Use this Exploration to record tiltmeter readings for volcano formed at a hot spot. Describe the data. If you were in charge of analyzing the data, how would you interpret it (what does it tell you about the volcano)?

**Answer:** The data show that the slope is constant in January and February, but begins to change in March. The slope increases significantly in April. I would infer that the magma is moving up inside the volcano, causing it to bulge outward. The volcano may be about to erupt.

**Note:** Students use the Exploration to answer this question.

8. EDM measurements are much more dangerous to take than tiltmeter measurements. Explain why.

**Answer:** The tiltmeter measurements are made automatically by the apparatus. The data is sent to a lab via radio signals. EDM measurements, however, require an actual person to survey the distance between benchmarks. People working on active volcanoes are in great danger because the volcano can erupt at any time. Even a minor eruption could kill or injure a person severely.

9. EDM and extensometer measurements may show an increase in distance or a decrease in distance before or during an eruption. Why might they show a decrease in distance?

**Answer:** The distance between two benchmarks could decrease if one side was tilted toward the other, or rotated toward the other.
10. What type of volcano is common in the east-central Africa? What do these volcanoes tell you about what is happening to the African continent in East-Africa?

**Answer:** Continental rift volcanoes are common in east-central Africa. Their presence indicates that that part of Africa is rifting, or splitting apart.

11. Compare the formation of magma at mid-ocean ridges with the formation of magma at subduction zones.

**Answer:** At mid-ocean ridges, magma forms as the crust thins and the plates move apart, causing the pressure to decrease on the mantle rocks below. The mantle rocks then melt and rise up. This is known as decompressional melting.

At subduction zone, magma forms when fluids such as water rise from the subducting oceanic plate and mix with the hot mantle and crustal rocks above. This decreases the melting temperature of those rocks, causing them to melt.

12. Identify one example each for volcanoes formed at:

a. Subduction zone

b. Hot spot

**Answer:**

a. Subduction zone: Mt. St. Helens, Mt. Pinatubo, Krakatoa, and Mt. Vesuvius

b. Hot spot: Hawaii and Yellowstone Caldera

13. Use this Exploration to record tiltmeter readings for a volcano formed at a subduction zone. Describe the data. If you were in charge of analyzing the data, how would you interpret it (what does it tell you about the volcano)?

**Answer:** The data show that the change in the distance between the benchmarks is gradual till 10th May, after which the distance changes drastically. I would infer that the magma is moving up inside the volcano, causing it to bulge outward. This occurred as the magma moved up, tilting the crater floor. The volcano may be about to erupt.

**Note:** Students use the Exploration to answer this question.
Hands-On Lab
Profiling Mid-Ocean Ridge Systems

Timing: one 90-minute class session

Objective(s):
Students will explore the bathymetric features of mid-ocean ridge systems and create their own bathymetric profiles from bathymetric maps.

Safety Precautions:
This lab poses no safety concerns.

Materials:
Per group:
- several sheets of graph or lined paper
- ruler
- image: Bathymetric Map: Three Islands
- image: Bathymetric Map: Explorer Ridge

Teacher Preparation:
Prepare print copies of the images Bathymetric Map: Three Islands and Bathymetric Map: Explorer Ridge for each group; students must be able to draw directly on these maps. Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.
Directed Inquiry

Before completing this lab, students should be able to explain the theory of plate tectonics and identify the main plate boundaries. At the beginning of the lab, divide students into pairs or groups of three. Instruct each group to create a concept map for the term *mid-ocean ridge* by brainstorming related geologic features and processes; for example, students may connect the central term *mid-ocean ridge* to the subcategories *divergent boundary* and *spreading center*, and connect these subcategories to more specific phrases such as “tectonic plates move apart” and “magma rises through gaps in sea floor.”

Discuss students’ ideas as a class, making sure students understand that mid-ocean ridge systems form at spreading centers and are characterized by prominent peaks on either side of a rift zone, or a divergent boundary where Earth’s crust moves apart. Explain that scientists can depict these features on bathymetric maps, or maps that represent the shape of the ocean floor. Like topographic maps, which represent the shape of dry land, bathymetric maps consist of contour lines. Each contour line aligns regions of equal elevation. For example, on a bathymetric map an island might be surrounded by contour lines that spread out like increasingly large ripples; each contour line represents an equivalent decrease in depth—for example, 20 m. Closely spaced contour lines represent steep features—e.g., where the land falls in 20-m increments over a short distance. Widely spaced contour lines represent features with a shallow grade—e.g., where the land falls in 20-m increments over a large distance.

Instruct each group to create its own bathymetric map on a piece of paper. Maps should meet the following criteria:

- There is at least one island
- From this island, the seafloor falls on all sides to a depth of 500 m
- On one side of the island, the seafloor has a very steep slope.
- On the other side of the island, the seafloor has a very gradual slope.
- Each contour line represents a decrease in depth of 100 m.
If necessary, students may use the following topographic maps as models:

- Topographic Map: Kasatochi Island
- Topographic Map: Earthquake Lake

- Topographic Map: Isolation Peak
Remind students that topographic maps show dry land, whereas bathymetric maps show the seafloor, but both use contour lines similarly. Emphasize that many different bathymetric maps can fulfill the criteria for this activity—there is not a single solution. This activity is simply to familiarize students with the concept of a bathymetric map. Here is one possible solution:

![Bathymetric Map Example]

Give groups 5–10 minutes to work on their maps, then have groups share their work with the class, discussing the different solutions and correcting any mistakes or misconceptions. Then, explain that scientists can also turn bathymetric maps into bathymetric profiles. A bathymetric profile is similar to the vertical rise and fall of a city along the skyline.
As an example, distribute to each group the image Bathymetric Map: Three Islands. Instruct students to locate the islands in the diagram and to identify the value of each contour line. (There are three islands, each shaded black. Each contour line represents a decrease in depth of 100 m.)
Explain that a bathymetric profile outlines the shape of the seafloor along a transect, or horizontal line, drawn across the bathymetric map. Instruct students to draw a transect across the center of their copy of the image Bathymetric Map: Three Islands and to label the transect AB, as shown below:
Next, students should place a piece of lined or graph paper along the transect. (It will be easier to work with the paper if students tape it to their bathymetric maps.) To create a bathymetric profile, students should follow these steps:

1. Draw a line on the y-axis of the paper to represent the vertical scale. Each tick mark along the y-axis represents one contour line in the bathymetric map.
2. Draw a horizontal line for the x-axis.
3. Move along the transect line (i.e., the x-axis of your paper). Every place a contour line crosses the transect line, place a mark at the appropriate place on the graph paper, as follows:
4. Finally, connect the lines on the graph paper to create a bathymetric profile illustrating the shape of the sea floor.

Instruct each group to share its work with another group; groups should note places where their profiles differ and discuss the possible reasons, as well as fix any correctable errors. Discuss the activity as a class, asking students to consider the advantages and disadvantages of using bathymetric maps and profiles to represent the sea floor:

Then you may decide to instruct groups to proceed to Guided Inquiry, where they will work with a different kind of bathymetric map.
Guided Inquiry
Instruct groups to review the image Bathymetric Map: Explorer Ridge.
Explain that Explorer Ridge is a spreading center in the northeast Pacific Ocean. In this location, the Juan de Fuca Plate and the North American Plate are moving apart, forming a mid-ocean ridge system with numerous undersea volcanoes. Instruct groups to discuss how this bathymetric map is different from the bathymetric maps used in Directed Inquiry. (Although the map of Explorer Ridge does label a few contour lines with depth measurements, most of the map is color-coded; for example, dark blue sections are approximately 1860 m deep, whereas red sections are approximately 1750 m deep. This map also contains two different scales, one of which identifies the vertical distance between each pair of contour lines and one of which identifies the horizontal distance between each pair of contour lines.)

Each group should draw one transect anywhere on its bathymetric map of Explorer Ridge, provided the transect crosses completely from one side of the map to the other (either left to right or top to bottom). Each group can develop its own plan for converting its selected transect into a bathymetric profile, based on members’ knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- Where will you draw your transect?
- What will be the range of your profile’s y-axis, and what will be your scale? (The bathymetric map shows a range of depths between –1740 m and –1900 m, and the map’s color key identifies a new depth every 20 m. Groups should not begin their profiles at 0 m; instead, they should skip directly to about –1700 m.)

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Describe the bathymetric profile for your initial transect A-B. The profile shows a variable bathymetry between transect A-B. The features are depicted by contour lines separated by an interval of 100 m. On either end of the transect are two islands. The island to the left of the profile is larger and has a very steep slope on one side; the island to the right of the profile is smaller and has a more gradual slope. A very small island with relatively steep slopes rises between the two “endpoint” islands.

2. Describe the bathymetric profile for your transect of Explorer Ridge. Students’ answers will vary depending on their transect, but they should note where the sea floor slopes steeply and where it slopes gradually, and they should note the locations of underwater mountains and valleys.
3. What kinds of information does a bathymetric profile present more clearly than a bathymetric map? What kinds of information does a bathymetric profile present less clearly?

Sample answer: With a profile, you can immediately see how the elevation and depth of a region changes—it’s like viewing a cityscape underwater. Because a bathymetric map shows an overhead view of a region, it is flatter and doesn’t immediately convey the shape of a region’s bathymetry. However, a bathymetric map can show an entire region, whereas a profile shows only a 2-dimensional transect of a region.

4. How could you improve your bathymetric profile of Explorer Ridge?

Answers will vary. Sample answer: Often we had to estimate the change in depth because the bathymetric map did not contain specific measurements for every section of the ocean floor; instead, the map used color to show changes in depth. To create more accurate profiles, we would need to obtain more complete data describing the depth across our entire region.
Inquiry and Nature of Science Skills in this Lab:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
  - Choose appropriate tools to conduct an investigation:
    - Ruler/tape Measure
  - Use the appropriate format to record data:
    - Chart
    - Writing (journal, worksheet, electronic text)
    - Sketch

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Graphed data points
    - Analysis of data collected during an investigation

- **Communication in Science**
  - Report results using:
    - Written report
    - Scientific explanations/arguments
    - Table/graph showing data

- **Scientific Endeavor**
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientific claims can be substantiated using data and observation.

- **Engineering and Technology**
  - Uses of Technology:
    - An invention can be used in different ways, such as a radio being used to get information and for entertainment.
    - Computers have sped up and extended people’s ability to collect, store, compile, and analyze data; prepare research reports; and share data and ideas with other investigators.
    - Human beings have made tools and machines, such as x-rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work

b) load data from another user by typing in the ‘Save Code’

c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Determining Average Atomic Mass

Timing: one 90-minute class session

Objective(s):
In this activity, students will be given three sets of coins, each of which represents a different isotope of an unknown element. Using the simulated isotopes, students will gather data and determine the average atomic mass of the element.

Safety Precautions:
Students should not put the coins or other objects in their mouths. Make sure students wear closed-toe shoes and eye protection during the investigation.

Materials:
Per group:
- 7 pennies (dated 1983 or later)
- 2 nickels
- 1 quarter
- laboratory balance
- notebook
- pencil

Teacher Preparation:
- Since the mass of a penny changed after 1982 (pre-1982, 3.11 g; post-1982, 2.50 g), use only pennies dated 1983 or later. The mass of a nickel is 5.00 g. The mass of a quarter is 5.67 g. If washers of different masses are substituted for coins, you will have to predetermine the mass of each variety of washer.
- If the number of laboratory balances is limited, you may wish to adjust the number of students per group so that each group has access to a balance.
- Prepare a copy of the Student Investigation Sheet for each student group.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Students should be told that the coins represent three isotopes of an element. The mass of each coin (or washer), which students will determine, represents the atomic mass of each isotope. The number of each type of coin represents the relative abundance of each isotope. Students will perform the following:

1. Use the balance to determine and record the mass of each “isotope.” Mass should be determined to hundredths of a gram.
2. Calculate and record the percent abundance of each “isotope.”
3. Use the data in Steps 1 and 2 to calculate the average atomic mass of each isotope.
4. Students will enter their data on the blank data table below.

<table>
<thead>
<tr>
<th>Coin (”isotope”)</th>
<th>Abundance (%)</th>
<th>Mass of ”isotope” (amu)</th>
<th>Average Atomic Mass (amu)</th>
</tr>
</thead>
<tbody>
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</tr>
</tbody>
</table>

Note: The table is blank for students to fill in their data.
After students have collected data and made their calculations, check their work for accuracy and understanding.

- Students should find the following masses: penny, 2.50 g, nickel, 5.00 g, quarter, 5.67 g.
- Students should find the following abundances: penny, 70%, nickel, 20%, quarter, 10%.
- Students should calculate the average atomic mass of the simulated element. (3.32 amu)
- Students should show the equation they used to determine the average atomic mass of the simulated element, that is:

\[
\text{Average atomic mass} = \frac{(70 \times 2.50 \text{ amu}) + (20 \times 5.00 \text{ amu}) + (10 \times 5.67 \text{ amu})}{100}
\]

\[
= \frac{331.7 \text{ amu}}{100} = 3.32 \text{ amu}
\]

- Students should repeat their measurements and calculations at least once.
- Students should share and compare and contrast their results with those of other groups, and determine causes of differences, if any.

Guided Inquiry
Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used.

- Each student group should select a number of different coins (or different washers) from each of three jars holding collections of these objects.
- Unlike in the Directed Inquiry, the total number of objects should not be divisible by 10 and should consist of at least 21 objects.
- The group should collect and record relevant data with which to calculate the average atomic mass of its “element.”
- The group should then pass its objects to another group, which simultaneously passes its objects to the first group.
- Each group will calculate the average atomic mass of the “element” it has received.
- Both groups will consult to compare and contrast results and procedures. If results do not match, the groups may repeat the investigation in search of errors or agreement.
- If results do not agree, the groups should discuss and identify possible errors in the procedures, and how they might have affected the results.

Ask the students some guiding questions to help them focus their inquiry:

- What does each kind of coin (or washer) represent? (a naturally occurring isotope of an element)
- What do the numbers of each coin (or washer) represent? (the abundance of each naturally occurring isotope of an element)
Extension Activity

Have each student bring in a handful of pennies. In this activity, all the coins will represent atoms of the same element, “penny.” Have students follow the procedure below, spelling out the steps if using Directed Inquiry, or allowing students to plan them on their own using Guided Inquiry.

1. Have students “purify” their sample by washing the pennies to remove dirt and other extra materials.
2. Instruct students to weigh one penny multiple times to determine the precision of the balance. The precision of the balances should be at least +/-0.05 g to allow identification of two different “isotopes,” one weighing about 3.1 g and one weighing about 2.5g. Have students use the information about the precision of the balance and the estimated weight of the pennies to determine a reasonable number of decimal places to use when reporting masses of pennies. (For students using Guided Inquiry, this also helps them determine a reasonable number of isotopes present.)
3. Have students select from their samples 10 pennies representing a wide variety of dates. Then have students weigh each penny individually and record the values. This should enable students to define general groups that represent isomers.
4. Have students find the average masses of their samples by weighing groups of coins and dividing by the number of coins. You might also encourage them to construct a data table to record individual weights for each coin and multiply to find the relative abundance of each “isotope.” The relative abundance calculation should give the same “average atomic mass” as the bulk weighing approach.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What sources of error might have affected your results? *(The mass of objects might have been incorrectly measured. The laboratory balance might be faulty. Calculations may have been made incorrectly, or the wrong equation was used.)*

2. With regard to your activity, what is an important scientific process that you used to confirm results of your team’s investigation? *(replication by another team; repetition of an investigation)*

3. Regarding communication, in what way did your team behave as scientists do? *(Our team shared its procedures and results with another team.)*
Inquiry and Nature of Science Skills in this Lab

- Identify Questions
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Can be answered with a science investigation or observational study

- Design Investigations
  - Design and conduct investigations using:
    - Multiple trials - repeated tests with the same variables to check for variability of results
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
    - Apply mathematical operations and principles to replicate the real thing
    - Are based on logic and evidence

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Balance
  - Use the appropriate format to record data:
    - Table

- Interpret Data
  - Identify and interpret patterns using:
    - Tables and graphs
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Examining how investigations can be improved

- Communication in Science
  - Report results using:
    - Peer presentation
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ New observations should be made when there is disagreement among initial observations.
    ▪ When a scientific investigation is repeated, a similar result is expected.
    ▪ Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
  o Scientific Data and Outcomes:
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Accurate record keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
    ▪ When similar investigations give different results, it often takes further studies to decide what is right.
• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ One way to make sense of something is to think of how it relates to something more familiar.
    ▪ Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
    ▪ An important part of science is the critical review and analysis of any idea or conclusion.
Concept: Parts of Atoms

Overview: You will identify and give examples of language structure.

Directions:

1. Work with a partner to explore the glossary terms "nucleus," "neutrons," "protons," and "electrons." Use the information from the Interactive Glossary to fill in the Words to Know chart below.

2. With your partner, write a sentence using each of the words.

3. With the help of your teacher and your partner, identify the language structure (such as the parts of speech of the words, the tense of the words, and the meanings of the words) of each of your sentences.

4. On your own, choose a sentence from the Explore section of "Parts of The Atom." Copy the sentence below and identify the language functions of the sentence.

What parts of the Techbook are you using? ________________________________

Who are you working with?

- the whole class
- a group
- one other person
- nobody

What will you have when you finish? ________________________________

Words to Know:

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>nucleus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>neutrons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>protons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>electrons</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Write your sentence for the word “nucleus” below.
What language structure and functions can you identify?

_________________________________________________________

Write your sentence for the word “neutrons” below.
What language structure and functions can you identify?

_________________________________________________________

Write your sentence for the word “protons” below.
What language structure and functions can you identify?

_________________________________________________________

Write your sentence for the word “electrons” below.
What language structure and functions can you identify?

_________________________________________________________

Write a sentence from the Explore section of “Parts of The Atom.”
What language structure and functions can you identify?

____________________________________________________________________________
Exploration Teacher Guide: Parts of the Atom

Overview

In this Exploration, students will explore how to build an atom or an isotope using subatomic particles. They will learn that stability of the nucleus depends upon the number of protons and neutrons. They also learn that the charge on an atom depends upon the difference, if any, between the atom’s number of protons and its total number of electrons.

Student Learning Objectives

- Observe how subatomic particles (protons, neutrons, and electrons) build an atom.
- Investigate the stability of the nucleus while building an atom.
- Learn about isotopes of an element.
- Explore the number of neutrons in the most abundant isotope of an element.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students have to build a stable and neutral atom or isotope. They also have to identify which element’s atom or isotope they build.

Protons, neutrons, and electrons are available. Students drag and drop protons and neutrons into the nucleus of the skeleton of the atom. The electrons are dragged and dropped into the shells. The electrons will snap to the correct shell when they are dropped. Protons, neutrons, and electrons are removed by dragging them out of the atom. The numbers of protons, neutron, and electrons are updated as they are added. The stability of nucleus is indicated when protons and neutrons are dragged into the nucleus. Students will be able to observe that the number of electrons is same as the number of protons for any neutral atom.

Student can build isotopes of an element by adding more neutrons to its nucleus. For each addition, they can observe the stability of the nucleus. Student can investigate the number of neutrons for each isotope of an element by removing or adding neutrons and observing the change in the stability of the nucleus.

The maximum number of protons, neutrons, and electrons that a student can add in the skeleton of an atom is 18, 22, and 18 respectively.

When the nucleus of the atom is stable, the Identify button becomes active. Students can use this button to identify which element’s atom or isotope they have built. However, they can only identify the element after a neutral atom or isotope is built. If the built atom or isotope is neutral, students can use the radio button options to identify the element correctly.
In the Tracker tab, students can review the atoms and isotopes that they have successfully built. Students can note the number of protons, neutron, and electrons added to form the atom or isotope.

Answers to questions in Student Worksheet

1. The charge and mass of three subatomic particles in an atom is given below. Identify if each of them is a proton, neutron, or electron. Also indicate where the particle is located within the atom.
   • Charge = (+) 1.60 x 10^{-19} Coulomb, mass = 1.67 x 10^{-27} Kg
   • Charge = (-) 1.60 x 10^{-19} Coulomb, mass = 9.10 x 10^{-31} Kg
   • Charge = 0 Coulomb, mass = 1.67 x 10^{-27} Kg

   Answer:
   • It is a proton as it has a positive charge and a mass of 1.67 x 10^{-27} Kg. It is located in the nucleus of the atom.
   • It is an electron as it has a negative charge and a mass of 9.10 x 10^{-31} Kg. Electrons orbit around the nucleus in electron clouds.
   • It is a neutron as it has no charge and its mass equals the mass of a proton. It is located in the nucleus of the atom.

2. The atomic number of sodium is 11 and its mass number is 23. List the number of protons, neutrons, and electrons in a neutral sodium atom.

   Answer: The atomic number of an atom represents its number of protons. A neutral atom has the same number of electrons as protons. The mass number is the sum of the number of protons and neutrons. Hence, a neutral sodium atom will have 11 protons, 11 electrons, and 12 neutrons.

3. Hydrogen, deuterium, and tritium are three isotopes of hydrogen. List the number of neutrons in each of these three isotopes.

   Answer: Hydrogen has three isotopes, and its most abundant isotope has no neutrons. Its isotopes deuterium and tritium have 1 neutron and 2 neutrons, respectively.

4. An atom has 13 protons, 13 neutrons, and 13 electrons. Another atom has 13 protons, 14 neutrons, and 13 electrons. Analyze and explain how these two atoms are related.

   Answer: Isotopes of an element have the same number of protons and electrons while they differ in the number of neutrons. These atoms are isotopes of one element as both have 13 protons and 13 electrons but they have a different number of neutrons.
5. How many electrons are in a neutral atom of an element that has 14 protons and 15 neutrons?

**Answer:** A neutral atom has the same number of electrons and protons. Since this is a neutral atom, it will have the same number of electrons as protons, 14.

6. Represent the oxygen atom symbolically along with its two isotopes that have 9 and 10 neutrons.

**Answer:** The oxygen atom can be represented symbolically as $^{16}\text{O}_8$ while its isotopes can be represented as $^{17}\text{O}_8$ and $^{18}\text{O}_8$.

7. Identify the part of an atom that is involved in chemical bonding.

**Answer:** The valence electrons, which usually reside in the outermost shell, are involved in the chemical bonding.

8. Calculate the atomic number of an element whose neutral atom has 4 electrons in its valence shell, and its valence shell is the M shell.

**Answer:** M shell is the third shell of an atom. This implies that the valence shell is the third shell. The first two shells can accommodate 2 and 8 electrons. Since the valence shell (third shell) has four electrons, the total number of electrons in the atom is 14 ($2 + 8 + 4$). A neutral atom has the same number of protons and electrons. The atomic number represents the number of protons in a neutral atom. So, the atomic number of this element is 14.

9. Identify what is required to calculate the atomic number and atomic mass of an element.

**Answer:** The atomic number represents the number of protons and the atomic mass represents the sum of the number of neutrons and protons. Hence, the number of protons and neutrons are required to calculate the atomic number and atomic mass of an element.

10. Explain what happens to an atom when protons are added or removed from its nucleus.

**Answer:** The number of protons defines the atomic number and each element has a unique atomic number. So, as protons are removed a new element will form and its position in periodic table will be toward the left of the original element. Similarly, a new element forms when protons are added. However, these elements will be toward the right of the original element in the periodic table.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.
- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
English Language Proficiency Activity

Concept: Arrangement of Electrons in the Atom

Overview: You will create a list of science vocabulary words and their meanings. You will use the list to help make sense of written text.

Directions:

1. Before you read the Explore section of “Arrangement of Electrons in the Atom,” create a list of the glossary words that are found in the lesson.

2. Work with a partner to use the Interactive Glossary to complete the Words to Know chart below.

3. Use your chart to help make sense of the glossary words as you read the Explore activities of “Arrangement of Electrons in the Atom.”

What parts of the Techbook are you using? ____________________________________

Who are you working with?

the whole class a group one other person nobody

What will you have when you finish? ____________________________________

Words to Know:

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

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Exploration Teacher Guide: Arrangement of Electrons in the Atom

Overview

Students will arrange electrons in orbitals to complete the noble gas configuration of atoms of various elements. They will also observe the quantum numbers of each electron.

Student Learning Objectives

- Identify how electrons are arranged in orbitals.
- Observe the noble gas configuration of elements.
- Examine the quantum numbers of electrons.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

Students select an element using options in the Select Element dropdown list. The symbol of the selected element with its atomic number and mass number is displayed. The selected element’s incomplete noble gas configuration is also displayed. Students drag valence electrons of the selected element from the Valence Electrons section and drop them into the empty s, p, d, and f orbitals. An electron dropped into any incorrect orbital, snaps back to the Valence Electrons section and the student is asked to try again. Once all the electrons are dropped correctly, students use the Continue button to examine the quantum numbers of all the electrons. Students do this by clicking on the electrons.

Students use the Hint button to view the complete electron configuration of the selected element.

They may use the Reset button to undo what they have done and start again.

In the Tracker tab, students observe the quantum numbers of the electrons present in the atom of various elements that they have explored.

Answers to Questions in Student Worksheet

1. Describe the relationship between the nucleus and energy levels of an atom.

   **Answer:** The energy levels of an atom are arranged as an electron cloud around the nucleus. The energy levels close to nucleus are the lower energy levels and those away from the nucleus are the higher energy levels. They are commonly denoted as s, p, d, and f.
2. Explain the Pauli exclusion principle.

**Answer:** The Pauli exclusion principle states that no two electrons in the same atom can be in the same quantum state. This means that no two electrons in an atom can have the same set of quantum numbers.

3. Compare and contrast Aufbau principle and the Pauli exclusion principle.

**Answer:** The Aufbau principle explains the order of filling of electrons in energy levels. It states that electrons fill the lower energy level before filling the higher energy level. Whereas, Pauli exclusion principle states that no two electrons in an atom can have the same set of quantum numbers.

4. List the quantum numbers that describe the energy level and the orbital shape of electrons.

**Answer:** The principal (n) quantum number describes the energy level of an electron. The azimuthal (l) quantum number describes its orbital shape.

5. Identify the maximum number of electrons that can be filled in the s, p, and, d orbitals.

**Answer:** The s, p, and d orbitals can accommodate a maximum of 2, 6, and 10 electrons, respectively.

6. Use the Exploration to fill the orbitals of chlorine with its valence electrons. Explore and list all four quantum numbers for the 10th electron of the chlorine atom.

**Answer:** The four quantum numbers of the 10th electron of a chlorine atom are:
- Principal quantum number: 2
- Azimuthal quantum number: 1
- Magnetic quantum number: 1
- Spin quantum number: $-\frac{1}{2}$

7. Use the Exploration to fill the orbitals of aluminum (Al) with its valence electrons. Identify the electron whose quantum numbers are $n = 3$, $l = 1$, $m_l = -1$, and $m_s = +1/2$.

**Answer:** The 13th electron of aluminum has quantum numbers $n = 3$, $l = 1$, $m_l = -1$, and $m_s = +1/2$.

8. Write the noble gas configuration for $^{30}$Zn (Zinc) and $^{35}$Br (Bromine).

**Answer:**
The noble gas configuration for $^{30}$Zn (Zinc) is [Ar] 4s$^2$ 3d$^{10}$.
The noble gas configuration for $^{35}$Br (Bromine) is [Ar] 4s$^2$ 3d$^{10}$ 4p$^5$. 
9. Write the electron configuration and identify the number of valence electrons in an atom of silicon ($^{14}\text{Si}$).

   \textbf{Answer}: The electron configuration of silicon is [Ne] 3s$^2$ 3p$^2$. It has four valence electrons.

10. The noble gas configuration of an element is [Ar] 4s$^2$3d$^{10}$4p$^2$. Identify this element.

   \textbf{Answer}: This electron configuration belongs to the element germanium (Ge).
Hands-On Lab
Hydrogen Spectrum Lab

Timing: one 90-minute class session

Objective(s):
In this lab activity, students calculate changes in energy that accompany specific electron transitions in the hydrogen atom. They use those energy values to calculate the frequencies and wavelengths of light emitted during those transitions, and match them to the hydrogen emission lines they observe in the lab.

Safety Precautions:
Students should be cautioned not to poke anything in the sockets of the hydrogen gas discharge tube. These tubes use extremely high voltages and must not be treated frivolously. Make sure students wear closed-toed shoes and eye protection during the investigation.

Materials:
Per class:
- colored markers
- handheld spectroscopes (4–5)
- hydrogen gas discharge tube (1)
- paper

If a hydrogen gas discharge tube and/or spectroscopes are not available, substitute paper copies of the hydrogen emission spectrum as shown in the sample data section below.

Teacher Preparation:
- Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
1. Pass out handheld spectroscopes and have students take turns using them to view fluorescent lights in the room. Fluorescent bulbs contain mercury, which emits a green line at 546 nm. This emission line can be used to check the accuracy of the spectroscopes. Adjustments should be made as needed to be sure that the spectroscopes provide an accurate reading of the mercury line.

2. Hold a brief class discussion about the role of the spectroscopes in this study. Ask students to describe what the fluorescent light looks like with and without the use of the spectroscope. Then ask them what the spectroscpe does to the light (disperses it into individual wavelengths).

3. Turn on the hydrogen discharge tube and have students make observations of the light. Explain that groups will be taking turns to view the light using their spectroscopes. When they do, ask them to record every emission line they observe using the colored markers. Provide a blank graph similar to the following that will make it easier for them to record their observations.

4. Construct a diagram of a hydrogen atom on the board by drawing four concentric circles around a small dot to represent the four energy levels around a hydrogen nucleus.
5. Ask students to imagine that an electron has been excited to the second energy level. It eventually returns to ground state by releasing energy in the form of light as it moves back to the first energy level.

6. Provide students with the value of ΔE for this transition: $-1.634 \times 10^{-18}$ J. Ask students the meaning of the negative sign on the result. (Energy is released.)

7. Ask students how the frequency and wavelength of the emitted light are related to its energy. Demonstrate how to calculate frequency and wavelength of light from its energy.

$$\Delta E = h\nu$$

$$\nu = \frac{\Delta E}{h}$$

$$\nu = \frac{1.634 \times 10^{-18} \text{J}}{6.626 \times 10^{-34} \text{Js}}$$

$$\nu = 2.47 \times 10^{18} \text{s}^{-1}$$

$$\lambda = \frac{c}{\nu}$$

$$\lambda = \frac{2.9979 \times 10^{8} \text{m/s}}{2.47 \times 10^{18} \text{s}^{-1}}$$

$$\lambda = 1.21 \times 10^{-7} \text{m}$$

$$\lambda = 121 \text{nm}$$

8. Tell students that the Lyman series results from electrons moving from energy levels 2 and higher down to the $n = 1$ level. Ask them to determine whether any of these transitions correspond to the wavelengths they observe in the hydrogen emission spectrum.

9. Provide the following blank data table that students will use to organize their calculations.

<table>
<thead>
<tr>
<th>$n_{\text{initial}}$</th>
<th>$n_{\text{final}}$</th>
<th>$\Delta E$ (J)</th>
<th>Frequency (s$^{-1}$)</th>
<th>Wavelength (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>$1.635 \times 10^{-18}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<td>1</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
Sample Data:

Sample Calculations

<table>
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<tr>
<th>$n_{\text{initial}}$</th>
<th>$n_{\text{final}}$</th>
<th>$\Delta E$ (J)</th>
<th>Frequency (s$^{-1}$)</th>
<th>Wavelength (nm)</th>
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<td>$2.466 \times 10^{15}$</td>
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<tr>
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<td>$2.136 \times 10^{-18}$</td>
<td>$3.221 \times 10^{15}$</td>
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</tbody>
</table>
Guided Inquiry
Students should be able to use their calculated results from the Directed Inquiry portion of the lab activity to conclude that no match exists between their results and their observed hydrogen emission lines. Students can then develop their own plans for collecting additional data, based on their knowledge of the procedure. Ask the students some guiding questions to help them focus their inquiry:

- Have you considered all of the possible electron transitions?
- How will you proceed to try to find the specific transitions that correspond to the emission lines you observed?

Each student should develop a plan to extend their table of calculations to explore the predicted wavelengths of light associated with other electronic transitions. Have students prepare a suggested table before they begin their calculations to gain your approval to move ahead. After you have approved a student’s plan, provide them with \( \Delta E \) values shown in the table below, and instruct the student to go ahead with their frequency and wavelength calculations.

Sample Calculations:

<table>
<thead>
<tr>
<th>( n_{\text{initial}} )</th>
<th>( n_{\text{final}} )</th>
<th>( \Delta E ) (J)</th>
<th>Frequency ((s^{-1}))</th>
<th>Wavelength (nm)</th>
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</tbody>
</table>

The highlighted region of the table indicates the emission lines that occur in the visible region of the spectrum. These lines should match the lines observed using the spectroscopes to view the light emitted by the hydrogen discharge tube.
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Did your calculated results match any of the spectral lines of hydrogen that you observed?
   *Four of the calculated wavelengths that were part of the \( n_{\text{final}} = 2 \) series matched the four observed wavelengths.*

2. Why didn’t you observe more of the calculated wavelengths? What accounts for these missing wavelengths?
   *The other wavelengths of light are outside of the visible region that humans can see. The wavelengths are not missing, but are not visible to humans so we do not detect them.*

3. What happened to the hydrogen atoms in the discharge tube to cause it to emit light?
   *The electrons in the hydrogen atoms absorbed energy from the electric current applied to the tube, which caused them to move to higher energy levels. These excited electrons then moved to lower energy levels, releasing energy in the form of light.*

4. Why do you see several wavelengths in the emission spectrum and not just one?
   *Electrons absorb different amounts of energy to move to different energy levels. Once they are in an energy level, they can move down to any of a number of different energy levels. This variation in movement to lower energy levels results in different wavelengths of light that correspond to the change in energy as excited electrons move to lower energy levels.*
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - Asks a question about a specific science concept or process
- Design Investigations
  - Design and conduct field studies using:
    - Survey – collects multiple data points at one point in time
  - Make or use models that:
    - Apply mathematical operations and principles to replicate a real thing
    - Are based on logic and evidence
  - Practice lab safety by:
    - Following lab safety procedures
- Gather Data
  - Choose appropriate tools to conduct an investigation:
    - Other Laboratory equipment (spectroscope)
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Sketch
- Evaluate Evidence
  - Draw and support a conclusion by:
    - Answering the testable question
    - Identifying alternative explanations
    - Examining how investigations can be improved
- Communication in Science
  - Report results using:
    - Table/graph showing data
- Patterns and Systems
  - Patterns and Change:
    - Things that change may do so in steady, repetitive or irregular ways.
    - Mathematical patterns help to predict future events and describe change in systems.
- Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
    - Scientific claims are based on data and reliable scientific sources.
    - Collecting and analyzing data is the best way to understand a changing pattern.
- Scientific Endeavor
  - Characteristics of Science:
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory* leads to looking at old observations in a new way.

A theory is a well-supported and widely accepted explanation for what is observed in the natural world.

- **Historical Perspectives:**
  - Theories are developed over time by the accumulation of evidence.
Hands-On Lab
Investigating the Dual Nature of Light

Timing: one 90-minute class session

Objective(s):
Students will investigate how different colors of light make a substance glow and use the results as evidence in support of a model to explain the nature of light.

Safety Precautions:
Remind students to follow all general lab safety rules, wear safety goggles and closed-toe shoes, and not to eat or drink anything in the lab. Students should follow all instructions for proper handling of electrical equipment. Students should not stare directly into any of the LEDs when lit. They should report any equipment malfunction immediately and should not try to fix any malfunctioning equipment by themselves.

Materials:
Per group:
- light-emitting diodes (LEDs), one of each of the following colors: red, yellow, green, blue, ultraviolet
- DC power supply
- light meter
- phosphorescent vinyl, one 5 cm × 5 cm square
- black construction paper, 2 sheets
- scissors or hole punch
- ruler
- graph paper, 10 sheets
- stopwatch or timer
- safety goggles, one pair per student
Teacher Preparation:

- Gather materials in advance of students performing the lab. A DC power supply, while expensive, can be obtained from a scientific supply provider. Check to see if your department has one that can be shared among science classrooms. LEDs and phosphorescent vinyl can also be purchased from a scientific supply provider and can be reused. Light meter apps are available for use with cell phones.
- Prepare a copy of the Student Investigation Sheet for each student.
- If time is limited, each pair of students can be assigned one LED to analyze. Once all pairs have completed their investigation, they can share their data so that all pairs will have data for all LEDs.

Procedure

This lab may be carried out using either a Directed Inquiry or Guided Inquiry approach. Both will be described below.

**Directed Inquiry**

1. Ask volunteers to describe the two models that have been proposed to describe light. Then, as a class, discuss how the two models differ and why they were proposed. (The particle model describes light as a continuous stream of particles, while the wave model describes light as an electromagnetic wave. Light interacts with matter in different ways; some of this behavior is consistent with one model and other behavior is consistent with the other model.)
2. Explain to students that the investigation they are about to carry out may provide evidence that supports one or both of these two models. Emphasize to students that they should keep both models of the nature of light in mind as they carry out the investigation.
3. Demonstrate how to use the power source to light the LEDs. During the investigation, students will vary the light intensity of the LED by varying the voltage. You can demonstrate this by showing students how the intensity of the light changes as you gradually increase the voltage. Make it clear that the voltage should never be raised above the maximum voltage that is needed to light the LED requiring the greatest voltage (i.e., the ultraviolet LED). Exposing LEDs to high voltages could destroy them.
4. Using the ultraviolet LED, demonstrate how a piece of phosphorescent vinyl glows after it is exposed to the light. Hold the LED very close to the plastic for 4 seconds. Students can punch holes in black construction paper to make masks that allow only small areas of the vinyl to be exposed to the light source.
5. Demonstrate how to use a light meter to take a light intensity reading of the glow produced by the LED exposure. This procedure must be carried out quickly because the glow fades quickly and students should try to measure the maximum glow produced. Immediately move the light meter to within 1 cm of the vinyl after the LED is removed. Record the highest light intensity reading showing on the meter.
6. Provide the following blank data table that students can use to organize their investigation. Students can construct one data table for each LED investigated.

<table>
<thead>
<tr>
<th>[Color] LED</th>
<th>Applied Voltage</th>
<th>Intensity of Glow</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page 2 of 5
7. Have students break up into pairs to begin their investigation. Have students take five intensity measurements for each LED, varying the voltage in small, regular increments (0.1–0.2 V). Circulate among pairs to answer questions and troubleshoot any equipment problems.

8. Once students have finished collecting data, have them prepare one graph for each LED showing the relationship between intensity of LED light output (as measured by the voltage input) and intensity of phosphorescent light glow output.

9. Have students discuss their results with their partners to determine whether the results provide evidence in support of either of the two models for the nature of light. If students struggle, you might wish to ask them to analyze whether the intensity of light was important in causing the glowing effect or the whether the wavelength of light was important. (The wavelength of light was critical in determining whether the glow would occur or not. Only the blue and ultraviolet light caused the vinyl to glow.)

10. Once students recognize the importance of the wavelength of light, ask them how the wavelengths of light differ. (Lower wavelengths are associated with higher energy and higher frequency light.) Ask them how this differs from other types of waves, such as water waves. (The energy of a water wave depends on its intensity.)

11. Explain to students that phosphorescence happens when an electron in an atom or molecule that excited to higher energy levels by light gives off light as it returns to the ground state. Ask students to explain whether their data supports either of the two models for the nature of light and how this relates to the electron energy levels. (The model supports the idea that light is made up of photons (particles) that have certain energies. Only photons with the right amount of energy can excite electrons to higher energy levels, which supports the idea that energy levels are quantized. Note that blue light and ultraviolet light excite electrons to different energy levels.)

Guided Inquiry
1. Proceed with steps 1-5 as described in the Directed Inquiry section.
2. Instead of providing students with blank data tables as described in step 6, have students work in pairs to discuss the various types of data that they will be able to collect using the equipment. Ask them to come up with variables that could contribute to the glow of the plastic. Then ask them to formulate questions about those factors, and to design an experiment to test their questions. Have students construct a data table to show the data they will collect to answer their questions. Ask them to discuss their ideas with you before they proceed with their investigation.
3. If students get off track, lead them back to the investigation of interest by asking them which two variables they can change in their setup and which variable the can measure to see how it changes. (We can change the color (wavelength or frequency) of the LED and the applied voltage/intensity of the LED and we can measure the intensity of the glow of the vinyl.)
4. Pick up with steps 7 – 8 as outlined in the Directed Inquiry section above to complete the lab.

Analysis and Conclusions
1. Did all of the LEDs produce the same effect on the phosphorescent vinyl? If not, did you observe a trend in the nature of the LEDs that produced effects and those that did not? Describe the trend you observed.

   The red, yellow, and green LEDs did not make the phosphorescent vinyl glow, whereas the blue and ultraviolet LEDs did. The ultraviolet and blue LEDs give off the lowest wavelengths and highest frequencies (highest energies) of the set of five LEDs tested.
2. What do your data indicate about what is required for light to make the phosphorescent vinyl glow?
The data show that the light must be at least a certain energy to cause a glow. Even if you increase the intensity of the lower energy LEDs, this does not stimulate the phosphorescent glow.

3. Do your results provide evidence in support of either the particle model of light or the wave model of light? Describe the evidence and explain which model it supports. Justify your answer by explaining why the evidence supports the model or models you claim it supports.
Sample answer: The results seem to fit the particle model of light. My reasoning is that there are two pieces of evidence: 1) light with a certain minimum level of energy causes the change, and 2) light with less energy than this minimum does not cause the change. An electron must be excited to a higher energy level for phosphorescence to occur. It can only be excited when it interacts with light that has enough energy. In the particle model of light, each particle, or photon, has a certain energy. When photons with the correct energy interact with an electron, they can excite the electron to a higher energy level. If light behaved only as a wave, then increasing the intensity would increase the energy and other colors would be able to cause a glow if they were intense enough.

4. Explain whether the conclusions you reached support current atomic theory.
They do support current atomic theory. My observations can be explained in part by the idea that electrons are in energy levels that have a certain energy, or are quantized. If electrons could be at an energy in an atom, then any wavelength of light would be able to cause the electron to be excited.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Develop question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - require the changing of one variable at a time.
    - can be answered with a scientific investigation or observational study.

- **Design Investigations**
  - Design and conduct investigations using:
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Graph or chart

- **Interpret Data**
  - Identifies and interprets
    - Trends in data
    - Graphed data points
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - reporting out trends and patterns in data.
  - Assessing the conclusion by:
    - answer the testable question.

- **Communication in Science**
  - Report results using:
    - Table/graph showing data

- **Patterns and Systems**
  - Patterns and Change:
    - Things that change may do so in steady, repetitive or irregular ways.

- **Scientific Investigation**
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
    - Scientific claims are based on data and reliable scientific sources.
    - Collecting and analyzing data is the best way to understand a changing pattern.

- **Scientific Endeavor**
  - Characteristics of Science:
    - Scientific claims can be substantiated using data and observation.
    - A theory is a well-supported and widely accepted explanation for what is observed in the natural world.
Objective:
Students will work in groups of four or five to work out the quantum numbers to assign each electron in an atom of neon.

Estimated time to complete: 15 minutes

Materials:
For each group of students:
- blank paper chart (4 columns × 11 rows)
- periodic table

Procedure:
Organize students in groups of four or five. Remind students how quantum numbers are related to energy level (n), type of orbital (\(\ell\)), orbital orientation (\(m_\ell\)), and electron spin (\(m_s\)). Instruct students to look up the element neon on the periodic table. Using information that they can obtain from the periodic table, ask students to write the quantum numbers for each electron found in an atom of neon.

Ask students to think about the following questions as they work:
- How many electrons are in one atom of neon?
- Does each electron have its own unique set of quantum numbers?
- Do any electrons have any quantum numbers in common?

Key:

<table>
<thead>
<tr>
<th>(n)</th>
<th>(\ell)</th>
<th>(m_\ell)</th>
<th>(m_s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>(-\frac{1}{2})</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>(+\frac{1}{2})</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>(-\frac{1}{2})</td>
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<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>(+\frac{1}{2})</td>
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<td>2</td>
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<td>(-\frac{1}{2})</td>
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<td>(-1)</td>
<td>(+\frac{1}{2})</td>
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<td>0</td>
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<td>2</td>
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<td>0</td>
<td>(+\frac{1}{2})</td>
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<td>1</td>
<td>(-\frac{1}{2})</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1</td>
<td>(+\frac{1}{2})</td>
</tr>
</tbody>
</table>

If necessary, repeat with other elements until students display confidence in determining the quantum numbers of electrons in the atoms of specific elements.
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Make or use models that:
    - Are based on logic and evidence

- **Patterns and Systems**
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Things that change may do so in steady, repetitive or irregular ways.
    - Many patterns in nature contain symmetry.
    - Symmetry may determine properties of many objects, such as molecules, crystals, organisms, and designed structures.
    - Mathematical patterns help to predict future events and describe change in systems.

- **Scientific Endeavor**
  - Characteristics of Science:
    - A theory is a well-supported and widely accepted explanation for what is observed in the natural world.
Exploration Teacher Guide: Quantum Mechanics

Overview

In this Exploration, students learn about the different orientations of the s, p, d, and f orbitals around x, y, and z axes. They also identify the quantum numbers of the orbitals.

Student Learning Objectives

- Examine different orientations of the s, p, d, and f orbitals around x, y, and z axes.
- Identify the values of the various quantum numbers related to all the orbitals.
- Investigate the differences between the structures of the various orbitals.
- Understand the relationship between orbitals and quantum numbers.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students examine different orientations of the orbitals around x, y, and z axes. They also identify the quantum numbers of the orbitals. Students select one of the four orbitals from the Select Orbital dropdown. They then select which orbital orientation to examine using the checkboxes in the Select Orbital Orientations section. Students may choose to examine more than one orientation at a time by selecting the corresponding checkboxes. They then check a radio button to identify the quantum numbers for each selected orbital.

Students may use the Reset button at any point, to clear all selections and return to the default selections of the dropdown and checkboxes.

Answers to Questions in the Student Worksheet

1. Explain the significance of the azimuthal quantum number.

   **Answer:** The azimuthal quantum number defines the shape of the orbital and gives the magnitude of the orbital angular momentum. This parameter plays a major role in dictating the bond angles and it therefore influences the chemical bonding of the atom.

2. List three major principles or rules that are followed in the conventional representation of quantum numbers.

   **Answer:** The Aufbau Principle, Hund’s Rule, and Pauli Exclusion Principle, are each used for the conventional representation of quantum numbers.
3. Explain the role of the value \( m_s \) in quantum mechanics.

**Answer:** The value \( m_s \) gives the magnetic spin constant of an orbital. The value can be either "spin up" or "spin down." In the case of spin of the electron, \( \frac{1}{2} = \text{spin up} \) and \( -\frac{1}{2} = \text{spin down} \).

4. Describe the differences between principal, azimuthal, and magnetic quantum numbers.

**Answer:** The principal quantum number defines orbital energy and size. The shape of the orbital is described by the azimuthal quantum number. The magnetic quantum number is an indicator of the orbital orientation.

5. Does the principal quantum number, \( n \), play a role in determining the value of \( m_l \) for a subshell? Explain your answer.

**Answer:** The value \( m_l \) does not depend on \( n \). This means that the principal quantum number does not play any role in determining the value of \( m_l \) for a subshell.

6. Which orbital orientation does the shape shown below represent?

![Figure 1: Identification of Orbital Orientation](image)

**Answer:** The \( f_y^3 \) orbital is represented by the shape shown above.

7. Explain the role of orbitals in defining the structure of the modern periodic table.

**Answer:** The modern periodic table is divided into s-block, p-block, d-block, and f-block elements. These groups are defined by the subshells occupied by the valence electrons of the elements in these groups.
8. Write the electronic configuration of calcium.

   **Answer:** The electronic configuration of calcium is 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 4s\(^2\).

9. List the formula that relates the magnetic quantum number (m_\(l_\)) with the azimuthal quantum number (l).

   **Answer:** The formula that relates m_\(l_\) with l is m_\(l_\) = 2l + 1.

10. Determine the maximum number of electrons that an orbital can hold.

    **Answer:** An orbital can hold a maximum of two electrons, irrespective of which shell it belongs to. These two electrons are always spin-paired.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students' skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Electron Configuration and the Periodic Table

Timing: one 90-minute class session

Objective:
In this activity, students will compare the electron configurations of various elements to their placement on the periodic table. They will also explore the orientation of the orbitals within the energy levels.

Materials:
Per student pair:
- paper copy of the periodic table
- colored pencils
- list of electron configurations for elements 1-54
- about 4 sphere-shaped balloons
- at least 7 teardrop-shaped balloons
- a handful of seeds or other small items that will fit easily through a balloon opening

Teacher Preparation:
Prepare a copy of the Student Investigation Sheet for each student.

Procedure
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.
Directed Inquiry:  
Have students complete the following procedure:

1. Refer to the list of electron configurations. For each element, circle or highlight the energy level with the highest number. This represents the outermost energy level of the element. The electrons at this level are the valence electrons.
2. Write the number of valence electrons in the empty column.
3. On a new blank sheet of paper, create a table containing eight columns. Title the columns in increasing order from left to right, starting with the number 1 and ending with the number 8.
4. Using the sheet with the list of electron configurations, place the atomic number and elemental symbol of the elements in each column depending upon the number of valence electrons that were determined previously. NOTE: Use only the elements where the electron configuration ends in s or p.
5. For each element that you have placed in columns 1 and 2 of your table, color their boxes on the periodic table green.
6. For each element that you placed in columns 3-8 of your table, color their boxes on the periodic table blue.
7. On another blank sheet of paper, create another table with two horizontal rows. Label these rows “3d” and “4d.”
8. In the 3d row, place all elements that have 3d electrons but no 4p electrons.
9. In the 4d row, place all elements that have 4d electrons but no 5p electrons.
10. For each element that you have placed in the 3d or 4d rows, color their boxes on periodic table red.
11. For each of the sections of the periodic table that you have already colored (columns 1 and 2, columns 3-12, columns 13-18) extend the shading to the bottom of the column. Ex: Color elements 55, 56, 87, & 88 the same color as the ones above them.
12. There should only be one section of the periodic table that is uncolored at this point, located at the very bottom of the table. Color these two rows of boxes orange.

Guided Inquiry:  
Using their understanding of electron configurations, students should now be able to transition to a three-dimensional view of electron configurations within orbitals.

Instruct students to use the seeds and the balloons to create three-dimensional models of electrons in their orbitals. Ask the students some guiding questions to help them focus their inquiry:

- What element will you model?
- How will the periodic table help you plan your model?
- Does the shape of the balloons matter? Why?
- How are the written configurations and the three-dimensional models similar?
- How are they different?
- What happens when the models of two atoms are joined together to model a molecule?
- How is the shape of the orbitals related to the shape of a molecule?
- How will you collect data about the orientation of the balloons in your model?

Sample s orbital model:  

Sample p orbital model:
Analysis and Conclusions:

1. Refer to the chart you created at the beginning of this activity.
   a. How many elements are in the horizontal rows that you created on your chart? How many elements are there in any "d" section on the periodic table?
      *There are 10 elements in each row and in any "d" section of the periodic table.*
   b. How many columns are there in the "s" section on the periodic table?
      *There are two columns of “s” sections.*
   c. How many columns are there in the "p" section on the periodic table?
      *There are six columns of “p” sections.*

2. Add the answers from the previous three questions together. What is the significance of this number?
   *The total number is 18. Eighteen electrons is the total number of electrons in s, p, and d orbitals in a given energy level.*

3. Consider the element barium (Ba).
   a. In which column of your first chart would you place barium?
      *Barium would go in the second column.*
   b. Write the electron configuration for barium (Ba).
      \[1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^2 \ 3d^{10} \ 4p^6 \ 5s^2 \ 4d^{10} \ 5p^6 \ 6s^2\]

4. Look at the lanthanide and actinide series located at the very bottom of the periodic table. How many elements are there in the row that contains the element cerium (Ce)?
   *There are 14 elements in this row.*

Challenge Questions:

5. Write the electron configuration for praseodymium (Pr). Check your answer using the chart you created.
   \[1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^2 \ 3d^{10} \ 4p^6 \ 5s^2 \ 4d^{10} \ 5p^6 \ 6s^24f^3\]

6. Write the electron configuration for lead (Pb). Check your answer using the chart you created.
   \[1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^2 \ 3d^{10} \ 4p^6 \ 5s^2 \ 4d^{10} \ 5p^6 \ 6s^2 \ 5d^{10} \ 4f^4 \ 6p^2\]

7. Predict the electron configuration for element #115.
   \[1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 4s^2 \ 3d^{10} \ 4p^6 \ 5s^2 \ 4d^{10} \ 5p^6 \ 6s^2 \ 5d^{10} \ 4f^4 \ 6p^6 \ 7s^2 \ 6d^{10} \ 5f^4 \ 7p^3\]

8. How is electron configuration related to the shape of a molecule?
   *The orientation of the orbitals determines how two atoms will come together. This determines the angle at which the bonds form and the shape of the molecule.*
<table>
<thead>
<tr>
<th>Atomic Number</th>
<th>Element</th>
<th>Electron Configuration</th>
<th>Number of Valence Electrons</th>
</tr>
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</tr>
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<td>1s^2</td>
<td>2</td>
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<td>8</td>
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</tr>
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<td>8</td>
</tr>
</tbody>
</table>
Inquiry and Nature of Science Skills in this Lab:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
    - Apply mathematical operations and principles to replicate the real thing.
    - Are based on logic and evidence
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Sketch

- **Communication in Science**
  - Report results using:
    - Scientific illustration with proper labeling

- **Patterns and Systems**
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Symmetry may determine properties of many objects, such as molecules, crystals, organisms, and designed structures.
    - Mathematical patterns help to predict future events and describe change in systems.
Overview

Lewis structures and energy level diagrams can be used to represent electrons in atoms of elements. In this Exploration, students create the energy level diagram of elements and observe their Lewis structures.

Student Learning Objectives

- Identify the electronic configuration and position of an element in the periodic table.
- Investigate whether the element obeys the octet rule.
- Observe the energy level diagram of the selected element.
- Examine the Lewis structure of the element.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students first identify the electron configuration of an element, its position on the periodic table, and whether it obeys the octet rule. They then create the energy level diagram of the element and observe its Lewis structure.

Twelve tiles appear on the screen. They are divided into four sets. The four sets are of elements, positions, electronic configuration, and octet rule applicability. Each set has three tiles. Students match the elements with their positions and electronic configurations by clicking on these tiles. Corresponding feedback is displayed, informing students whether their choices are correct or incorrect. After correctly matching all the tiles, they click the Proceed button to continue with the Exploration.

The Select Element dropdown is used to select an element for which students wish to create the energy level diagram. They can then drag and drop the orbitals to the correct energy level. These must be dropped in the correct order by observing the electron configuration. Once the energy level diagram is correctly filled, students are informed of their success through the feedback. They now click the Continue button to add electrons to the orbitals. Students can do this by clicking on the orbitals in the correct order. While the students are clicking on the orbitals to create the energy level diagram, they can simultaneously observe the Lewis structure for the selected element. The Start Over button can be used to undo changes to the current run and restart it from the beginning. The Reset button can be used to generate a new random set of elements for identification and creation of energy level diagram.
Students can use the Tracker tab to track the electronic configuration of correctly identified elements, their position in the periodic table, number of valence electrons, and whether they obey the octet rule. Students can use the buttons provided to observe their Lewis structure.

**Answers to Questions in Student Worksheet**

1. Explain the term electron configuration.

   **Answer:** Electron configuration of an atom of an element is the arrangement of electrons of that atom around its nucleus. The electrons are arranged in energy levels or orbitals.

2. List the information you can obtain by observing the electron configuration of an atom.

   **Answer:** The information that can be obtained by observing the electron configuration of an atom is:
   - Number of occupied energy levels.
   - Orbital type within an energy level.
   - Number of electrons in each orbital.
   - The number of valence electrons.

3. State and explain the octet rule.

   **Answer:** The octet rule states that elements will react if they have less than eight electrons in their valence shell. This means that elements react and combine to have eight electrons in their valence shell and attain stable electronic configuration of a noble gas.

4. List the maximum number of electrons that can be present in one level of the s, p, d, and f orbitals.

   **Answer:** The maximum numbers of electrons that can be present in the s, p, d, and f orbitals are 2, 6, 10, and 14, respectively.

5. Name two p block and two d block elements.

   **Answer:**
   - p block elements: Oxygen, Fluorine.
   - d block elements: Chromium, Iron.

6. Write the electron configuration of argon. The atomic number of argon is 18.

   **Answer:** The electron configuration of argon is 1s$^2$ 2s$^2$ 2p$^6$ 3s$^2$ 3p$^6$. 
7. Write the order of filling electrons in orbitals of an atom.

   **Answer:** The order of filling electrons in orbitals of atoms is 1s 2s 2p 3s 3p 4s 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p.

8. Differentiate between a filled and an unfilled orbital.

   **Answer:** A filled orbital has a pair of electrons with opposite spins. An unfilled orbital is either empty or has one electron.

9. Identify the maximum number of d orbitals that can be present in an energy level. Also, identify the maximum number of d electrons that can be present in an energy level.

   **Answer:** There can be a maximum of five d orbitals and a maximum of ten d electrons in an energy level.

10. Write the electron configuration of magnesium and identify the block to which it belongs. Also, comment on its octet rule applicability.

    **Answer:** The electron configuration of magnesium is \(1s^2 2s^2 2p^6 3s^2\). It belongs to the s-block and obeys the octet rule.
English Language Proficiency Activity

Concept: Electron Representation

Overview: You will listen and watch a video segment. You will work with a partner to share your questions and work together to find answers.

Directions:

1. Listen and watch the video segment "Determining Electron Orbit."
2. Take notes on the information that you heard and saw in the video.
3. Write one or two questions you have from the video.
4. Work with a partner to find and discuss the answers to each other’s questions from the video.
5. Present the questions and answers that you and your partner had to the class.

What parts of Techbook are you using? ________________________________

Who are you working with?
the whole class  a group  one other person  nobody

What will you have when you finish? ________________________________

Words to Know: Add key words and a picture or example to help you remember each word.

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>electron</td>
<td></td>
<td></td>
</tr>
<tr>
<td>orbital</td>
<td></td>
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</tbody>
</table>
English Language Proficiency Activity

Write three things that you know about Periodic Trends:

• 
• 
• 

Write one question that you cannot answer about the video segment.

____________________________________
____________________________________
Hands-On Activity
Energy Levels

Objective: to explore the energy of electrons at different locations relative to an atom’s nucleus

Safety note: Perform this activity in an area where the swinging string will not hit any people or objects. Ensure that other students stand far away from any student swinging a string.

Estimated time to complete: 10 minutes

Materials:
For each small group of 3-4 students:
- 1 length of string, 2 m
- 1 small object such as a washer, clothes pin, etc.

Procedure:
Have students attach the object securely to the string, and check their knots before they begin the activity. Have one student in each group swing the object around in an orbit above their head, holding the string at its halfway point (about 1 meter from the object). Have the student describe for their group the amount of strength they feel it takes to hold the object in orbit, by assigning the effort a value on a scale of 1-5. They might also describe the effort or motion needed to keep the string in motion, and how their hand and arm feel.

Have the students stop swinging the string and move their grasp to the end so that the object is about 2 meters away. Have them swing the object around again and describe the strength required to keep the object in orbit, based on a scale of 1-5. They might compare the effort or motion needed to keep the string in motion during this trial, as well as how their hand and arm feel.

Students should conclude that it takes more energy to swing the string farther away from their bodies than close to their bodies. Emphasize to students that in this model, their hands or bodies do NOT represent the nucleus of the atom or its charge. Remind them also that electrons do not move in planar orbits; they move randomly throughout three-dimensional orbitals. This activity only describes the energy of electrons located farther from the nucleus. The higher the energy of an electron, the more likely it is to be located farther from the nucleus of an atom.
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
  - Practice lab safety by:
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use senses to observe:
    - Touching (temperature, texture, shape, size, vibration, motion)
    - Kinesthetic (balance, position)
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students' skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table."

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Development of the Periodic Table

Overview

In this Exploration, students develop a periodic table using elements known during Mendeleev’s time. They investigate how physical and chemical properties of elements are used to develop a periodic table.

Student Learning Objectives

- Analyze physical and chemical properties of elements.
- Examine the arrangement of elements in rows and columns according to similar properties.
- Understand trends such as atomic mass.
- Investigate undiscovered elements and where they are placed on the periodic table.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students position elements on the periodic table in a similar manner to that of Mendeleev as he developed his periodic table. A few elements are represented in the table throughout. A set of ten new elements are available in each run of the Exploration.

Students use the Previous and Next buttons in the navigation pane to view the missing elements one by one. The physical and chemical properties of the selected element are displayed below. In each run of the Exploration, at least one element from the set of missing elements is an element that was undiscovered during Mendeleev’s time. Students drag the element icon from the navigator pane and drop it into its correct position in the periodic table. They use the Check button to validate if they correctly placed elements in the periodic table. Element icons may be removed or switched around the periodic table by dragging.

The Hint button may be used to see hints on how to arrange elements on the periodic table.

The Reset button undoes what the user has done with the current set of missing elements. The Start Over button restarts the activity with a new set of elements.

In the Data tab, students examine the various physical and chemical properties of the elements that they added to the table.
Answers to Questions in the Student Worksheet

1. List two features of Mendeleev’s periodic table that led to its widespread acceptance.
   
   **Answer:** Mendeleev’s table was widely accepted because it had the most consistent arrangement of elements and also accounted for undiscovered elements.

2. How does the modern law of periods differ from Mendeleev’s law of periods?
   
   **Answer:** Modern periodic law arranges the elements based on their atomic numbers and Mendeleev’s periodic law arranges the elements based on their atomic masses.

3. Use the periodic table to determine the odd one out of these four elements: C, Si, Ti, Na.
   
   **Answer:** Na is the odd one out.

4. Use the periodic table to group these twelve elements into six pairs of elements having similar properties: Ca, K, Ga, Br, Bi, Sn, Cl, Al, Rb, Si, P, Sr.
   
   **Answer:** Ca and Sr, K and Rb, Si and Sn, Cl and Br, P and Bi, and Ga and Al.

5. Rank the following elements in order of decreasing boiling point: Sr, B, and N.
   
   **Answer:** B, Sr, N.

6. How does the valence of elements vary as you move across a period?
   
   **Answer:** Valence of an element increases as one moves across the period.

7. What are the modern names of the three ‘undiscovered elements’ that Mendeleev predicted would later be identified?
   
   **Answer:** Ekaboron, Ekaaluminum, and Ekamanganese.

8. Write down the oxides formed by nitrogen and molybdenum. Explain why nitrogen forms more oxides as compared to molybdenum.
   
   **Answer:**
   
   Oxides of Molybdenum: MoO₂, MoO₃.
   Oxides of Nitrogen: N₂O, NON₂O₃, N₂O₅ N₂O₄
   Nitrogen forms more oxides as compared to molybdenum since its valence is greater than molybdenum.
9. How does the atomic mass of elements change as you move across a period?

**Answer:** Atomic mass of elements increases as one moves across a period.

10. An element has a valence 3 and atomic mass 44.96 amu. Identify this element. Which elements are placed to the left and right of this element on the periodic table?

**Answer:** The element mentioned in the question is Sc. The element to its right is Ti and to its left is Ca.
Concept: Structure of the Periodic Table

Overview: You will practice understanding spoken text. You will work with a partner to learn new vocabulary words.

Directions:

1. Watch the video “Elements on The Periodic Table” with closed captioning [CC].

2. As you watch, write down new and unfamiliar words that you hear and read.

3. Use the Words to Know Chart below to write down information about the words. (You may pause, go back (rewind), and watch the video more than one time.)

4. Share your chart with a partner. Does your partner agree with the information you added to your chart? Are there words on your partner’s chart that you could add to your chart?

5. With your partner, use the Interactive Glossary and help from your teacher to check the meanings of the words in your chart.

What parts of Techbook are you using? _______________________________

Who are you working with?

the whole class  a group  one other person  nobody

What will you have when you finish? _______________________________
**English Language Proficiency Activity**

**Words to Know:**

<table>
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<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
<th>What helped me understand the word? (Reading the closed captions or Listening to the video)</th>
</tr>
</thead>
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<tr>
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</tbody>
</table>
Hands-On Activity
Engineering and Design: Designing a System

Students will work in groups in this mock product development activity. They need to work together to develop a thermometer that can detect changes in temperature within a given range. To do this, they will need to generate a list of material properties that are necessary for a thermometer to function in the desired temperature range. They will then choose an element that has the required properties and present their product development plan to the class.

Suggested Materials
Per Group:
- periodic table
- tables of melting and boiling points
- paper and presentation materials
- thermometers, a variety of types and temperature ranges, if possible

To introduce the activity, provide time for students to look at the example thermometers and discuss how a thermometer works. Point out that liquid in glass thermometers consist of an enclosed glass tube with a reservoir at one end. The reservoir is filled with a material that expands or contracts as it is heated or cooled and gradations on the tube relate the expansion to changes in temperature. A bimetallic thermometer is made by layering two different metals in a long strip or coil that is fixed at one end. When the temperature changes, one metal expands or contracts more than the other and the metal strip bends. A gas thermometer detects changes in pressure of an enclosed gas as it expands or contracts in response to changes in temperature. Other types of thermometers also exist but are not practical to discuss in this activity. Do not reveal too much about the properties of the materials since that is the primary focus of this activity.

Procedure:
Assign each group one of the following target temperature ranges:
- a. -90°C – -50°C
- b. -20°C – 80°C
- c. 0°C – 1000°C
- d. 1500°C – 2400°C

Use the Think-Pair-Share approach to encourage students to think about the problem as an engineer would by considering the requirements of the problem they need to solve and the limitations of the materials that they might use. Ask: Who is likely to use your thermometer? What are the requirements of a thermometer? How does the temperature range affect your choice of materials? After groups share their ideas with the class, instruct students to follow the steps below.

1. List the requirements and possible challenges of a thermometer for your temperature range.
2. Based on these requirements and limitation, decide which type of thermometer to develop.
3. Identify the parts of the thermometer that you would need to make.
4. List the properties that are required for each of the materials you would need to make a thermometer in the assigned range.

5. Determine which group of elements is most likely to contain materials with the necessary properties (e.g., metals, nonmetals, and/or metalloids).

6. Propose the elements you would use to construct your thermometer, taking into consideration health, environmental, and safety impacts.

7. Prepare a presentation that you will present to class to propose your product plan. Include a graph to show the melting points of the materials you chose and a diagram showing the parts of your thermometer. Be prepared to defend the materials you chose based on their properties.

Analysis and Conclusions

All questions should be included in the students' reports and may be mentioned during their presentations.

1. List the requirements and possible challenges of a thermometer for your temperature range.
   All thermometers need to be able to accurately measure the temperature.
   a. -90°C – −50°C: The thermometer needs to work at very low temperatures. The materials need expand and contract enough to show a temperature difference.
   b. -20°C – 80°C: The thermometer needs to work below the freezing point of water. The materials need expand and contract enough to show a temperature difference.
   c. 0°C – 1000°C: The thermometer needs to work over a large temperature range. It needs to work at relatively high temperatures where many common liquids might boil and solids might melt.
   d. 1500°C – 2400°C: The thermometer needs to work over a large temperature range. It needs to work at high temperatures where many solids might melt. Glass could be a liquid at this temperature.

2. Based on these requirements and limitation, decide which type of thermometer to develop.
   a. -90°C – −50°C: a liquid-in-glass thermometer is reasonable
   b. -20°C – 80°C – a liquid-in-glass thermometer is reasonable and a bimetallic thermometer may be possible
   c. 0°C – 1000°C – a liquid-in-glass thermometer may be possible or a bimetallic thermometer
   d. 1500°C – 2400°C – a bimetallic thermometer

3. Identify the parts of the thermometer that you would need to make.
   For a liquid in glass thermometer: a solid, clear material for the outside and a liquid inside that will expand
   For a bimetallic thermometer: two solids that expand and contract at different rates, plus materials for the gauge

4. List the properties that are required for each of the materials you would need to make a thermometer in the assigned range.
   For a liquid-in-glass thermometer:
   a. The material inside the thermometer must be a liquid for the target temperature range; melting point below lower limit; boiling point above upper limit.
   b. All of the material cannot be very reactive OR care will need to be taken to fill the empty space in the tube with an inert gas.
   c. The materials need to be stable at the given temperature and should not decompose.
d. The outside material needs to be a solid in the given temperature range.

For a bimetallic thermometer:

a. The materials need to be metals can expand and contract differently in the given temperature range.
b. The metals need to have melting points well above the highest temperature in the range.
c. The metals need to be very stable so they do not react over time or at high temperatures.

5. For each part of your thermometer, propose elements that have all of the necessary properties. Proposed materials may vary; proposed liquid elements should have melting points below and boiling points above the temperature range for liquid-in-glass thermometers. Solids should be metals that are solids in the given temperature range, meaning melting points above the highest temperature. Below is listed at least one element which will work for each temperature range:

a. -90ºC – −50ºC – Chlorine
b. -20ºC – 80ºC – Mercury
c. 0ºC – 1000ºC – Gallium
d. 1500ºC – 2400ºC – Iron, Tin, Lead

6. Are there health, environment, or safety concerns you need to consider related to the element you have chosen for your thermometer? Answers will vary depending on the element chosen. Chlorine, mercury, and lead are toxic.
In this activity, students will demonstrate the following Inquiry Skills:

- **Communication in Science**
  - Report results using:
    - Peer presentation
    - Written report
    - Scientific illustration with proper labeling

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating a conclusion

- **Patterns and Systems**
  - Patterns and Change
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- **Scientific Investigation**
  - Scientific Data and Outcomes
    - People are more likely to believe ideas if good reasons are given for them.
    - Scientific claims are based on data and reliable scientific sources.

- **Scientific Endeavor**
  - Characteristics of Science
    - Scientists are curious about wanting to know how things work.

- **Engineering and Technology**
  - Uses of Technology
    - Each part of a mechanical device contributes to the purpose of that device.
  - Engineering Design
    - Any invention may lead to other inventions.
    - Human beings have made tools and machines, such as x-rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
    - Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
Hands-On Lab
Structure of the Periodic Table

Timing: one 90-minute lab session

Objectives:
In this students will:
• Collect data on the properties of the elements
• Predict properties of elements
• Graph the data (by hand or graphing tool) to show how a property can be modeled with a mathematical function
• Analyze the data, compare the data to their predictions, and input information into a periodic table.

Materials:
Per individual, pair, or group:
• multiple sheets of graphing paper
• blank copies of the periodic table

Teacher Preparation:
This activity works well for small groups of 2–3 students. You will need to prepare a blank version of the periodic table and make copies and/or an overhead transparency; alternatively, students can draw their own periodic table to fill in.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.
Directed Inquiry
To begin, lead a class discussion about the structure of the periodic table. Show a blank periodic table and ask students to share what they know about the general shape and structure of the table. Ask their help in adding column and period labels. Label groups (noble gases, halogens, transition metals, etc.) and element types (metal, metalloid, nonmetal).

Next, students take turns calling out the names of a few elements that are familiar to them. Add the symbols for these elements into their proper places in the table. Then consult the table Properties of the Elements (below) or other resources and add some information about selected properties of those elements (such as atomic mass, ionic radius, atomic number, boiling point, etc.).

Organize students into pairs or small groups. Each group selects one property and creates a graph illustrating how the property varies by element. (See the example graph of atomic mass, below.) Students can draw the graph by hand or use a graphing tool.
Ensure that students can explain key features of the graph, including their choice of which units to use, scaling the axes and the type of function.

**Atomic Mass of the First 10 Elements**

Discuss with the class the meaning of the graph. Have students predict the properties of elements on the period table that lie close to the elements that appear on the graph.
**Guided Inquiry**
Students work in pairs or small groups to analyze the periodic table. For example, they may select a set of periods or groups; metals, nonmetals, or metalloids; or another set of their own choosing. Groups choose two or three properties to examine and then make a prediction about those properties. Students create graphs that illustrate the properties among the set of elements they have chosen.

Ask the students some guiding questions to help them focus their inquiry:

- What properties will you analyze?
- What do you predict the relationship will be within rows or columns?
- What do you predict the relationship will be within types of elements?
- What type of mathematical function is represented by your graph?

You may wish to provide materials, including physical chemistry textbooks and periodic tables (with additional data such as electronegativity and atomic radii) to allow students to compare and contrast properties of elements and classify the elements into groups or periods.

If time allows, students can continue to work with additional sets of elements and complete the entire periodic table in this manner.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What properties of elements are predictable within rows? *Answers may vary. Possible answers include atomic mass and proton number increase from left to right within rows, etc.*

2. What properties of elements are predictable within groups? *Answers may vary. Possible answers include increasing atomic mass and proton number moving from top to bottom within a group, etc.*

3. What are some ways you could identify an unknown element if you knew its mass, boiling point, or other physical properties? *Answers may vary. Possible answers include the use of a graph to pinpoint where these known properties fit – such as the element having an atomic mass that falls in between two known elements.*

4. How is the periodic table structured? *Answers may include 7 rows, 18 groups; elements exhibit periodicity and there are identifiable trends (such as boiling point) that allow the properties and behavior of an element to be predicted.*
## Properties of the Elements

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<thead>
<tr>
<th>Atomic Number</th>
<th>Atomic Mass</th>
<th>Element</th>
<th>Symbol</th>
<th>Melting Point</th>
<th>Boiling Point</th>
<th>Density (g/cm³)</th>
<th>Ionization Energy (eV)</th>
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etc.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Gather Data**
  - Use the appropriate format to record data:
    - Table
    - Graph
    - Chart
    - Writing (journal, worksheet, electronic text)
    - Sketch
    - Diagram

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic
    - Applying a classification scheme to objects, substances or organisms
    - Developing a classification scheme for objects, substances or organisms
  - Identify and interpret patterns using:
    - Trends in data
    - Repeating physical or data patterns
    - Graphed data points
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Identifying alternative explanations
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Explaining how technology can be used to enhance the investigation
    - Showing the application of the scientific concept or process being investigated

- **Communication in Science**
  - Report results using:
• Peer presentation
• Written report
• Scientific illustration with proper labeling
• Images or video
• Audio recording
• Scientific explanations/arguments
• Table/graph showing data

• Patterns and Systems
  o Patterns and Change:
    ▪ Many patterns in nature contain symmetry.
    ▪ Symmetry may determine properties of many objects, such as molecules, crystals, organisms, and designed structures.
  o Scientific Data and Outcomes:
    ▪ People are more likely to believe ideas if good reasons are given for them.
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Collecting and analyzing data is the best way to understand a changing pattern.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ Scientists are curious about wanting to know how things work.
    ▪ Scientific claims can be substantiated using data and observation.
    ▪ Scientific theories are based on accumulated evidence.
    ▪ An important part of science is the critical review and analysis of any idea or conclusion.
  o Scientific Discoveries:
    ▪ Mendeleev
Overview

The periodic table is a system for organizing elements. In this Exploration, students learn why elements are positioned in specific locations of the periodic table. They observe the trends in various properties of the elements across the table and assign the positions of particular groups of elements.

Student Learning Objectives

- Identify the various groups of elements in the periodic table.
- Observe the structure of the periodic table and assign the positions of groups of elements.
- Observe the trends in properties of these elements across groups and periods.
- Understand the relationship between position of elements in the periodic table and their properties.
- Observe how elements with similar properties are grouped together in the table.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students position sets of elements to build the periodic table. Each set contains elements within a specific group. Students browse through the available sets of elements using the Previous and Next buttons on the navigator. A set can be dragged to any vacant position in the periodic table. Students may use the Check button at any time during the Exploration to validate the positions of the sets. Upon validation, correctly positioned sets are color-coded based on their classification. The correspondingly colored interactive keys are also enabled. Students may use the interactive key to highlight the corresponding group of elements. Incorrectly positioned sets are marked with a red border around the elements. Students click on the incorrectly placed sets to move them back to the navigator. Alternatively, they may click on the Remove button to remove all incorrect sets from the table at once. They may use the Reset button at any point during the Exploration, to empty the periodic table completely and restart the process of arrangement of elements and the Show Atomic Number checkbox to display atomic numbers of various elements.

In the Data tab, students compare the properties of various groups of elements. These properties include atomic number, table period, melting point, boiling point, malleability, ductility, conductivity, and the tendency to lose electrons.
Answers to Questions in the Student Worksheet

1. List three distinguishing properties between metals and nonmetals.

   **Answer:** Metals are malleable, ductile, and have high melting and boiling points. Nonmetals are neither malleable nor ductile, and have comparatively lower melting and boiling points.

2. Elements in the modern periodic table are arranged based on their atomic numbers. Which other properties were used to arrange elements in earlier attempts to classify them? Why were they discarded?

   **Answer:** Mendeleev's periodic table was arranged on the basis of atomic weights of elements. However, arranging elements on the basis of atomic weights results in inconsistencies of chemical properties within groups. The modern periodic table is therefore organized by atomic number.

3. Explain why lanthanides and actinides are placed in two rows separate from other elements in the periodic table.

   **Answer:** These elements are placed in Group 3B. The 3B elements are the first elements to begin filling the d shell electrons in their electron configuration.

4. Identify which properties vary horizontally (in periods) and which ones vary vertically (in groups) in the periodic table. Refer to the information from the Data tab for your answer.

   **Answer:** Atomic radius increases vertically (within a group), but decreases horizontally (within a period) in the periodic table. On the other hand both electronegativity and ionization energy increase horizontally and decrease vertically.

5. Give examples of radioactive elements. What is their position in the periodic table?

   **Answer:** Uranium is an example of a radioactive element. Most but not all radioactive elements are known as transuranic elements and are in the 3B group of actinide metals. Polonium and radon are examples of radioactive elements that are not in the 3B group.

6. Describe the trend of ionization energy in the placement of elements across the periodic table.

   **Answer:** Elements are placed in increasing order of ionization energy across periods. Down groups, they are placed in decreasing order of ionization.
7. How are recently discovered elements named?

**Answer:** Recently discovered elements are named after famous scientists. These include rutherfordium, bohrium, and roentgenium.

8. Comment on the atomic radius of elements within groups. Compare this with the trend of atomic radius across periods. Explain what you infer from this comparison. Refer to the information from the Data tab for your answer.

**Answer:** The atomic radius decreases across periods because increasing number of electrons in the outermost shell increases the force of attraction between the positively charged nucleus and the negatively charged electrons. On the other hand, atomic radius increases within groups as more and more shells are added to the atoms of elements.

9. Describe the relationship between ionization energy and atomic number of elements.

**Answer:** Ionization energy and atomic radius of elements are directly proportional. This means that as the atomic radius of elements increases, their ionization energy also increases.

10. Explain how the periodic table accounts for isotopes of elements.

**Answer:** The periodic table provides the atomic weight for the stable isotopes of all naturally-occurring elements. It does not account for their other isotopes. Among elements with no known stable isotopes, the periodic table includes the atomic weight for the longest-lived isotope (e.g. $^{98}\text{Tc}$, $^{237}\text{Np}$).
Hand-on Lab
Structure of the Periodic Table

Timing: one 90-minute lab session

Objective(s):
In this activity, students will collect data on the properties of elements. They will predict properties of elements, graph and analyze the data, compare the data to their predictions, and input information into a periodic table.

Materials:
Per individual, pair, or group:
- multiple sheets of graphing paper
- blank copies of the periodic table

Teacher Preparation:
This activity works well for small groups of 2–3 students. You will need to prepare a blank version of the periodic table and make copies and/or an overhead transparency; alternatively, students can draw their own periodic table to fill in.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
To begin, lead a class discussion about the structure of the periodic table. Show a blank periodic table, and ask students to share what they know about the general shape and structure of the table. Ask their
help in adding column and period labels. Label groups (noble gases, halogens, transition metals, etc.) and element types (metal, metalloid, non-metal).

Next, have students take turns calling out the names of a few elements that are familiar to them. Add the symbols for these elements into their proper places in the table. Next, consult the table Properties of the Elements (below) or other resources, and add some information about selected properties of those elements (such as atomic mass, ionic radius, atomic number, boiling point, etc.) Select one property, and creating a graph illustrating how the property varies by element. (See the example graph of atomic mass, below.)

Sample graph:

**Atomic Mass of the First 10 Elements**

Discuss with the class the meaning of the graph. Have students predict the properties of elements that on the period table lie close to the elements that appear on the graph.

**Guided Inquiry**

Have students work in pairs or small groups to complete an additional portion of the periodic table. For example, they may select a set of periods or groups; metals, nonmetals, or metalloids; or another set of their own choosing. Have them choose two or three properties to examine, and then make a prediction.
about those properties. Finally, have the students create graphs that illustrate the properties among the set of elements they have chosen.

Ask the students some guiding questions to help them focus their inquiry:
- What properties will you analyze?
- What do you predict the relationship will be within rows or columns?
- What do you predict the relationship will be within types of elements?

You may wish to provide materials, including physical chemistry textbooks and periodic tables (with additional data such as electronegativity and atomic radii) to allow students to compare and contrast properties of elements and classify the elements into groups or periods.

If time allows, students can continue to work with additional sets of elements and complete the entire periodic table in this manner.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What properties of elements are predictable within rows? Answers may vary. Possible answers include atomic mass and proton number increase from left to right within rows, etc.

2. What properties of elements are predictable within groups? Answers may vary. Possible answers include increasing atomic mass and proton number moving from top to bottom within a group, etc.

3. What are some ways you could identify an unknown element if you knew its mass, boiling point, or other physical properties? Answers may vary. Possible answers include the use of a graph to pinpoint where these known properties fit – such as the element having an atomic mass that falls in between two known elements.

4. How is the periodic table structured? Answers may include 7 rows, 18 groups; elements exhibit periodicity and there are identifiable trends (such as boiling point) that allow the properties and behavior of an element to be predicted.
Properties of the Elements

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<th>Ionization Energy (eV)</th>
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</table>

etc.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- Gather Data
  - Use the appropriate format to record data:
    - Table
    - Graph
    - Chart
    - Writing (journal, worksheet, electronic text)
    - Sketch
    - Diagram

- Interpret Data
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic
    - Applying a classification scheme to objects, substances or organisms
    - Developing a classification scheme for objects, substances or organisms
  - Identify and interpret patterns using:
    - Trends in data
    - Repeating physical or data patterns
    - Graphed data points
    - Tables and graphs
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Identifying alternative explanations
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Explaining how technology can be used to enhance the investigation
    - Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
- Peer presentation
- Written report
- Scientific illustration with proper labeling
- Images or video
- Audio recording
- Scientific explanations/arguments
- Table/graph showing data

- Patterns and Systems
  - Patterns and Change:
    - Many patterns in nature contain symmetry.
    - Symmetry may determine properties of many objects, such as molecules, crystals, organisms, and designed structures.
  - Scientific Data and Outcomes:
    - People are more likely to believe ideas if good reasons are given for them.
    - Scientific claims are based on data and reliable scientific sources.
    - Collecting and analyzing data is the best way to understand a changing pattern.

- Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
    - An important part of science is the critical review and analysis of any idea or conclusion.
  - Scientific Discoveries:
    - Mendeleev
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Concept: Periodic Trends

Overview: You will understand new science content and words. You will develop a deeper understanding of the Periodic Table.

Directions:

1. You should work through the video segments and Exploration, Periodic Trend, in the Explore section of the concept Periodic Trends.
2. If you need help understanding what is written, you can click on the “Speak Text” button.
3. Use the Interactive Glossary for support to help understand the terms.
4. When reading the text, use the text to speech feature for support.
5. Quiz your partner on the information to confirm understanding.

What parts of Techbook are you using? ________________________________

Who are you working with?

the whole class   a group   one other person   nobody

What will you have when you finish? ________________________________

Words to Know: Add key words and a picture or example to help you remember each word.

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>trend</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Write three things that you know about Periodic Trends:

• _________________________________________________________________________

• _________________________________________________________________________

• _________________________________________________________________________

Write one question that you cannot answer about the video segment:

___________________________________________________________________________

___________________________________________________________________________
Hands-On Lab
The Periodic Trend of Reactivity

**Timing:** one 90-minute laboratory session

**Objective(s):**
Students will observe the trend in reactivity with water within the alkali metals. Students will investigate the trend in reactivity with water within the alkaline earth metals and across period 3.

**Safety Precautions:**
Due to safety concerns with the reactions of sodium and potassium with water, the first portion of the lab should only be done as a demonstration. This lab uses metals that react exothermically with water. Remind students to orient all reactions away from their face and partner. The reactions of the metals with water produce bases. Remind students to follow all general lab safety rules, wear closed-toe shoes, and not to eat or drink anything in the lab. Students should never leave the lab area unattended with chemicals sitting out. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for disposal and cleaning of the chemicals and their containers. Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

**Materials:**
For demonstration:
- Sodium metal under oil, 1 piece
- Potassium metal under oil, 1 piece
- Beakers, 2 500mL
- Distilled water, 200 mL
- Phenolphthalein
- Forceps
- Knife, sharp
- Paper towels

Per pair:
- Beakers, 4 50 mL
- Hotplate, 1 for every 2 pairs
- Forceps
- Spatulas, 2
- Aluminum strip, 2.5 cm
- Calcium granules, 25 mg
- Magnesium ribbon, 2.5 cm piece
- Sulfur powder, 25 mg
- Phenolphthalein in dropper bottle
- Distilled water, 100 mL
- Safety goggles, one pair per student
- Lab apron, one per student
- Disposable gloves, one pair per student
Teacher Preparation:
• Gather materials in advance of students performing the lab.
• Cut aluminum and magnesium metals to the desired sizes before distribution to the students.
• Note: The phenolphthalein does not react with the elements, but is used to help students observe the signs of reaction in boiling water.
• Disposal: Prepare waste containers to dispose of materials following state and district protocols. Reactions of metals with water produce basic solutions.

Part 1: Teacher-Led Demonstration

Procedure

Leave samples under oil until the start of the demonstration.

1. Add 100 mL of water to each beaker. Add 2-3 drops of phenolphthalein to each beaker, explaining to students that it is an indicator that changes color when a base is formed during a reaction. Position one of the beakers so the students can easily see it (on a projector, if possible).
2. Remove a piece of sodium metal from the oil with forceps and place it on the paper towel. Cut it half with a knife. Have the students make observations about the appearance of the metal sample, focusing on color and luster. Ask: How does the appearance of the freshly cut portion differ from the rest of the sample? What do you notice about the physical properties of the metal as it is exposed to air? What in the air might be causing this change? What does this tell you about the reactivity of the metal?
3. Hold the sodium with forceps and cut off a small piece (2-3 mm per edge). Return the larger pieces to the oil. Use the paper towel to rub the excess oil of the smaller pieces. Ask: What do you notice about the ease with which I was able to cut the metal?
4. Before beginning this step, be sure students are far enough away from any possible spray or sparks from this demonstration. Drop the sodium in the beaker of water and instruct the students to make observations. Focus on indicators of chemical reactions and length and vigor of the reaction.
5. Using the other beaker of water, repeat steps 2 – 4 with the potassium metal. Ask: How did the reactions between water and sodium and water and potassium differ? Which element is more reactive? What would you expect to observe during a reaction of lithium and water? Cesium and water?

Part 2: Student Investigation

Procedure

1. Obtain samples of aluminum, calcium, magnesium, and sulfur.
2. Observe the color and luster of the samples. Record your observations in your data table.
3. Add about 50 mL of water to each of the 100 mL beakers. Add 2-3 drops of phenolphthalein to each beaker.
4. Use steel wool or fine sandpaper to clean the reacting surface of the aluminum strip and the magnesium strip. Be careful to hold the strips by their edges to avoid oils from your hand. One at a time, use the forceps or spatula to add each element to a separate beaker. Record your observations in your data table.
5. If no reaction occurred in Step 4, heat the beaker on a hotplate set to 110ºC until the water boils. Record your observation in your data table.

6. Dispose of all solutions and solids as instructed by your teacher.

Analysis and Conclusions

1. Based on your observations, what can you infer about the trend of reactivity down a group in the periodic table? 
   Potassium was more reactive with water than sodium. Calcium reacted with cold water, while magnesium only reacted with hot water. Therefore, reactivity increases from the top to the bottom of a group for both the alkali and alkaline earth metals.

2. Based on your observations, what can you infer about the trend of reactivity across a period of the periodic table?
   Sodium reacted vigorously with cold water, magnesium only reacted with hot water, and aluminum and sulfur did not react at all with water. Therefore, the reactivity decreases from left to right across the group. However, only one nonmetal, sulfur was tested, and the halogens are the most reactive nonmetals.

3. Explain how atomic size and number of valence electrons contributes to the trend in reactivity you observed in each group.
   Atoms in the same group tend to react similarly because they have the same number of valence electrons. Metals react by losing valence electrons because they have relatively low ionization energies. The alkali metals and alkaline earth metals would react with water to form positive ions. The nuclear charge increases moving down a group. However, the atomic radius also increases as the number of energy levels increases causing the valence electrons to move further away from the nucleus. The valence electrons are also shielded from the nucleus by the inner electrons. As a result, reactivity increases going down each group because valence electrons are more easily removed.

4. Explain how atomic size and number of valence electrons contributes to the trend in reactivity you observed across the period.
   The nuclear charge increases moving across a period, which increases the attraction for the electrons and makes them more difficult to remove. The number of electrons that need to be removed to achieve an octet also increases. As a result, reactivity of metals tends to decrease across a period. Periods also contain nonmetals at the right of the periodic table. Unlike metals, nonmetals react by gaining valence electrons. Sulfur would not react with water to form a positive ion. Instead, sulfur would react with water by gaining electrons and would achieve an octet by gaining two electrons. Because sulfur did not react with water, it must not gain electrons readily.
In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use

- **Gather Data**
  - Choose appropriate tools to conduct an investigation:
    - Beakers and test tubes
    - Hot plates
    - Forceps
  - Uses the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns:
    - Trends in data

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting out trends/patterns in data

- **Communication in Science**
  - Report results using:
    - Written report

- **Patterns and Systems**
  - Patterns and change:
    - Patterns in nature may be simple repeating patterns or complex changing patterns
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
Exploration Teacher Guide: Periodic Trends

Overview

The periodic table is a system for organizing elements. Properties of elements change systematically within the table. In this Exploration, students compare properties of elements as they move across a period (row) and down a group (column). They observe trends in atomic radius, ionic radius, ionization energy, and electronegativity.

Student Learning Objectives

- Observe that atomic radius increases down a group and from right to left across a period.
- Observe that ionic radius increases down a group and from left to right across a period.
- Observe that first ionization energy increases down a group and from right to left across a period.
- Observe that electronegativity decreases down a group and increases left to right across a period.
- Compare the trends of atomic radius, ionic radius, first ionization energy, and electronegativity between groups and periods.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students observe trends in properties of elements across periods and within groups of the periodic table. Students select a property they want to explore using the radio buttons available. The selected property can be investigated with a group (column) or across a period (row). When an element is selected, the corresponding group and period are highlighted. Students roll over or swipe horizontally or vertically other elements to highlight others in the same group or period. Students select another element in the same group or period to stop selecting. The value of the selected property for each selected element is displayed and also plotted on a corresponding graph. Students review the data on the graph to determine the trend of the relevant property in the selected group or period.

In the Data tab, students review trends by selecting a group or period from the dropdown list. The data table shows the atomic radius, ionic radius, first ionization energy, and electronegativity of the elements in the selected group or period.

In the Graph tab, students select a group or period from the dropdown list to observe thumbnails of graphs for the four periodic trends for the selected group or period. Students can see an expanded view of that graph by clicking on the graph thumbnail.
Note that for both the *Data* and *Graph* tabs, the lanthanides and actinides are available as options, independent of Group 3 or Periods 6 and 7.

**Answers to Questions in the Student Worksheet**

1. Select *Atomic Radius* as the property and select an element in period 3. Go across (left to right) period 3 and interpret how the atomic radius generally changes. Explain your observation.

   **Answer:** The atomic radius in period 3 decreases from sodium on the left to chlorine on the right. This is because the number of electrons in the third shell increases from left to right, so the force of attraction between the positively charged nucleus and negatively charged electrons increases. Due to this force of attraction, the shells are pulled towards the nucleus and the atomic radius decreases. The atomic radius slightly increases from chlorine to argon due to the mutual force of repulsion between the eight outermost electrons.

2. Select *Ionic Radius* as the property and select an element in period 4. Go across (left to right) period 4 and describe the change in ionic radius across the period.

   **Answer:** The ionic radius decreases from potassium to germanium in period 4. Then it increases sharply for arsenic, declining slightly for selenium and bromine.

3. Select *Ionic Radius* as the property and select an element in group 13. Go down group 13 and describe the general trend in ionic radius.

   **Answer:** Ionic radius increases from boron to thallium.

4. Select *Electronegativity* as the property and select an element in period 3. Go across (left to right) period 3 and describe how the electronegativity generally changes. Explain your observation.

   **Answer:** Electronegativity increases from sodium to chlorine in period 3. An increase in the positive nuclear charge results in an increase in the attraction between the nucleus and the valence electrons, causing an increase in electronegativity.

5. Rank the following elements in decreasing order of electronegativity: K, Li, Cs.

   **Answer:** The electronegativity decreases from Li to Cs as follows: Li (0.98 Pauling units), K (0.82), Cs (0.79).
6. Explain why electronegativity increases from left to right across a period.

**Answer:** Electronegativity increases across a period because an increase in the nuclear charge increases the attraction between the nucleus and the valence electrons.

7. How do changes in atomic radii with changes in electronegativity correlate down a group or across a period? Use the Data or Graph tab to make this observation.

**Answer:** Atomic radii and electronegativity of elements are inversely proportional. This means that as the atomic radius increases, electronegativity decreases.

8. Write down the first ionization energy for fluorine and iodine. Why does fluorine have a higher first ionization energy than iodine?

**Answer:** The first ionization energy for fluorine is 17.42 eV, whereas that for iodine is 10.45 eV. The first ionization energy is the amount of energy required to remove the outermost electron from a neutral atom. The outermost electron of fluorine is in the second shell and that of iodine is in the fifth shell. Because the outermost electron of fluorine is nearer to the nucleus, it is more closely bound to the nucleus as compared to that of iodine.

9. How do periodic trends in electronegativity correlate with those for first ionization energy? You may use the Data or Graph tab to make this observation.

**Answer:** The electronegativity and first ionization energy are directly proportional. This means that as the electronegativity of elements increases, their first ionization energy also increases.

10. On the sketches of the periodic table, draw arrows showing group trends in atomic radius, ionic radius, electronegativity, and first ionization energy.

**Answer:**

[Diagram showing trends in atomic radius and ionic radius]
Electronegativity

First Ionization Energy
Hands-On Lab
Periodic Trends

**Timing:** one 90-minute session

**Objective(s):**
In this activity, students will perform several tests to determine the chemical and physical properties of various elements. Students will gather and record data, analyze patterns, and identify an unknown sample based on their scientific observations.

**Safety Precautions:**
Remind students to wear goggles, gloves, and lab aprons, and not to eat or drink anything in the lab. Tell students to report any spills or broken glass and not to clean it up themselves. This lab uses concentrated hydrochloric acid, and precautions should be followed while using and disposing of this hazardous chemical.

**Materials:**
Per class:
- conductivity meters or volt meters, one or more
- hammers, small, one or more
- watch glasses, one or more
- dropper bottles of 0.5 M HCl, one or more
- balances, one or more
- tweezers for each station
- test tubes with rack (enough test tubes for each group to test each sample)
- element samples, approximately 25 g of each of the following samples, labeled:
  - carbon
  - tin
  - silicon
  - sulfur
  - iron
  - gold
  - aluminum
  - nickel
  - copper
  - zinc
  - silver
  - ceramic
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Ion Formation

Overview

Ions are charged atoms or molecules. In this Exploration, students observe the charge ions as electrons are added or removed from the valence shell of atoms. Students add or remove electrons for a variety of atoms to identify whether the ion formed is a cation or an anion.

Student Learning Objectives

- Investigate how ions are formed.
- Examine the charge on ions when electrons are added or removed.
- Observe the ion formed and determine whether it is a cation or an anion.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students form ions by adding electrons or removing electrons from the valence shell of atoms. They observe the charge on the ion and identify whether the ion formed is a cation or an anion.

Students select an atom from the Select Atom dropdown list. The atomic structure of the selected atom appears in the activity area. A smaller grayed out image of the same atom also appears on the top right corner of the activity area. This image remains unchanged while its corresponding atom is in the activity area. Students use this small image to compare it with the ion they are forming. Students drag and drop electrons from or into the Electrons Available window to add or remove electrons to or from the valence shell of the atom. If all the electrons are removed from the outer shell, the shell disappears. Students may click the Add Valence Shell button to restore the outer shell. The indicated charge on the ion keeps changing as electrons are added or removed. Students validate the ion formed using the Check button. After building an ion correctly, students click on the appropriate button to identify the formed ion formed as a cation or an anion.

In the Tracker tab, students review the ions they formed. They note the number of added or removed electrons for specific elements, the resulting charge on the ion and whether the ion is a cation or an anion.
Answers to Questions in the Student Worksheet

1. Describe how ions are formed. Explain why they are different from atoms.
   
   **Answer:** Ions are formed when atoms’ outer electron shell lose or gain electrons. The loss or gain of an electron from a neutral atom causes the atom to have a positive or negative charge. Ions have a more stable electron configuration than their respective atoms.

2. What is the difference between a cation and an anion?
   
   **Answer:** A cation is a positively charged atom formed when an atom loses an electron. An anion is a negatively charged atom formed when an atom gains an electron.

3. Explain why ions have a charge on them.
   
   **Answer:** Ions are formed when electrons are lost or gained. An electron has a negative charge. The ion develops a charge because the number of electrons present in the atom is not equal to the number of protons in the positively charged nucleus of the atom.

4. Explain why ions are more stable than their corresponding atoms.
   
   **Answer:** Stability is achieved when the number of electrons in the atom’s outer shell is equal to that of the closest noble gas configuration. Most lower period atoms form stable ions with eight electrons in their valence shell. They lose or gain electrons to complete the octet and form ions. Thus, ions are more stable than their corresponding atoms.

5. Why do metals form cations and nonmetals form anions?
   
   **Answer:** Metals have only one, two, or three electrons in their outermost shell. It is easy for metals to lose electrons to attain a stable electron configuration. Thus, metals form cations. Nonmetals have six or seven electrons in their outermost shell and gain electrons to attain a stable electron configuration. Thus, they form anions.

6. Explain how the charges on ions can be predicted by examining elements in the periodic table.
   
   **Answer:** The charge on an ion depends on the number of valence electrons required for the atom to have a stable electron configuration. The periodic table can be used to identify the relevant number of valence electrons. This number, in turn, determines the charge. For example, group I elements require one valence electron for a stable electron configuration. So, they lose one electron to form a cation with a charge of plus one.
7. Select sodium from the Select Atom section. Add four electrons to its valence shell. Remove electrons from its valence shell. Explain your observations.

   **Answer:** If four electrons are added to the valence shell, the sodium atom acquires a charge of -4, which is not stable. A stable sodium ion is formed if one electron is removed from the valence shell.

8. Identify the effect of ion formation on the size of the atom.

   **Answer:** The size of an atom increases if it forms an anion. Its size decreases if it forms a cation.

9. Select fluorine from the Select Atom section. Remove electrons from its outermost shell. Analyze and explain the change in the charge on the ion. Is this ion likely to form during a chemical reaction?

   **Answer:** The fluorine atom develops a positive charge when electrons are removed from the valence shell. This kind of positive ion will not form during a chemical reaction. This is because it is easier for a fluorine atom to gain an electron, rather than lose one, to attain a stable electron configuration.

10. Describe how the ionic compound sodium chloride is formed.

    **Answer:** The ionic compound sodium chloride is formed when the sodium ion loses an electron and becomes a sodium cation and the chlorine atom gains an electron and becomes a chlorine anion.
Hands-On Lab
Ion Formation and the Octet Rule

Timing: one 90-minute class session

Objective(s):
In this activity, students will explore the scientific process and the development of models in the context of ion formation.

Safety Precautions:
If students use sharp objects or tools to build their models, they should wear safety goggles and take precautions to avoid puncture wounds.

Materials:
Per group:
- copy of the periodic table
- drawing materials
- three-dimensional spheroids, such as peas, marbles, or balls of modeling clay
- construction materials, such as lengths of wire, tape, and glue

Teacher Preparation:
You might want to suggest that students bring in materials to use in the models along with the basic classroom supplies you have available.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.
Directed Inquiry
Display an atomic diagram of the sodium atom and the sodium ion. Begin a class discussion, asking students:
1. “How did the sodium atom become an ion?”
2. “What element has atoms with the same number of electrons as the sodium ion?”
3. “Why do you think atoms form ions?”

Next, display the oxygen atom and ion. Have the students work in small groups for about five minutes to create a short skit that demonstrates formation of an oxygen ion. After each group performs their skit, have the rest of the class provide feedback about both the content of the skit and the way it was presented. Be sure to address any misconceptions that become apparent during this class discussion.

Next, discuss with the class the function of models. Ask, How was the model in the skit accurate? How was it inaccurate? Guide the discussion to transition into the topic of pros and cons of models illustrating ion formation. Ask, What details are needed to make a model about ion formation useful? What details can be ignored for a model about this topic?

Now divide the class into small groups, and have each group select three elements from three different families of the periodic table, making sure they use at least one metal and one nonmetal. Show the class the materials you have collected for them to use. Instruct them to create models that show an ion of each element they have chosen. The models should include details about the octet rule and about basic atomic structure. Students should also compare and contrast formation of metal and nonmetal ions.

Guided Inquiry
Students will use models of their own design to complete one of the two tasks below. When completing either assignment, students should follow the scientific process to predict how their model will work, document a procedure for developing the model, test the design, and refine the design to make any improvements that they can. To test the design, they should apply it to elements located in different areas of the periodic table, and should then make conclusions about why the model is or is not useful.

Option 1: Students will work in small groups to develop an original game to teach fifth graders about ion formation and the octet rule. The game must include some kind of model. Ask the students some guiding questions to help them focus their inquiry:
- Considering your audience for the game, what factors should you think about when designing your game?
- How are models incorporated into other games you play?
- How will you determine whether the fifth graders have really learned about ion formation?
Option 2: Tell students the following: Imagine that you travel to another universe and discover an entirely new set of elements there. After some research, you and your group determine that the chemical properties of the elements you have found are not governed by the octet rule. Instead, another rule determines the behavior of atoms. Choose a rule that you would like to model, such as a sextet rule, a quintet rule, or some other kind of rule entirely. Use your model to illustrate how elements on the new planet form ions. Discuss with your group how the properties of Earth’s elements might change if they followed the new rule, and create a poster or other presentation comparing the new rule with Earth’s octet rule.

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. How are models helpful when learning new concepts? They enable you to see concrete illustrations of the concept. Also, it helps to see different peoples’ ideas about the concept in the models they create.

2. How do the atoms of nonmetals become ions? They gain electrons to form a complete octet of valence electrons.

3. How do the atoms of almost all metals become ions? The atoms of almost all metals lose valence electrons to form a complete octet of valence electrons.

4. What does the group to which an element belongs allow you to predict about ions? The group to which an element belongs can be used to predict the type of charge (positive or negative) on the ion and the magnitude of the charge.
Inquiry and Nature of Science Skills in this Lab:

- **Design investigations**
  - Explain the investigative process by:
    - describing the logical sequence that was used to conduct the investigation.
    - properly citing all equipment and materials.
  - Make or use models that:
    - simulate a real thing that cannot easily be studied or manipulated.
    - have as many details as possible replicated from the real thing.
    - function exactly like or similarly to the real thing.
    - are based on logic and evidence.
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use

- **Communication in Science**
  - Report results using:
    - images or video
    - scientific explanations/arguments

- **Patterns and Systems**
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Some events can be predicted with certainty, such as sunrise and sunset, and some cannot, such as storms.
    - Things that change may do so in steady, repetitive or irregular ways.
Data/Graph Tool
Teacher’s Guide

Introduction

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How to Use the Data/Graph Tool

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Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

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When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

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When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

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Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Ionic Bonding

Overview

Ionic bonds form between metal and nonmetal atoms with a significant difference in electronegativity. In this Exploration, students identify the valence of various elements to understand the role of valence in ionic bonding and form ionic bonds. They also observe the crystal lattice structure of the compounds formed.

Student Learning Objectives

- Identify possible combinations of metals and nonmetals that form ionic bonds.
- Observe the resulting cations and anions formed due to ionic bonding.
- Understand the electronegativity difference between atoms in the ionic bond.
- Observe the lattice structure of various ionic compounds.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students create an ionic bond between various metals and nonmetals, using available elements in the dropdown lists. The elements in the Select Metal list are sodium, magnesium, potassium, calcium, and lithium. The elements in the Select Nonmetal list are chlorine, fluorine, oxygen, sulfur, and nitrogen.

When the Exploration begins, sodium and chlorine are selected by default. One atom of each is provided in the activity area. Atoms may be removed from the activity area using the Remove button (X in the top right of each atom’s image). More atoms of the metal or nonmetal in the dropdown list may be added using the corresponding Add button. A maximum of six atoms may be added to the activity area. If the selected element is changed, all instances of the previously selected element are replaced with one instance of the newly selected one.

To build an ionic bond, students drag and drop valence electrons from the metal atom to the valence shell of the nonmetal atom. The electrons may only be dragged from the metal's valence shell, and dropped in the nonmetal valence shell. When the electron is transferred, the element symbol updates to show the ion formed by addition or removal of the electron. On selecting the Show Electronegativity checkbox, the electronegativities of the selected metal and nonmetal, along with their electronegativity difference are displayed. Students may use this to observe that in most cases, ionic bonds form between atoms that have a minimum electronegativity difference of 1.7 Pauling units.

Students use the Check button to validate if an ionic bond has formed correctly. When the required number of electrons has been transferred from the metal atom(s) to the nonmetal
atom(s), the bond and the crystal lattice structure of the compound formed may be observed using the View Animation button.

The Reset button replaces all actions performed by the user with one instance of the currently selected metal and nonmetal atom.

In the Tracker tab, students review the various ionic compounds they have created successfully. Displayed properties of the formed compounds include their cations and anions, electronegativity difference between the elements, and the compound’s chemical formula. Students use the button in the Link column to observe the ionic bond formation and the crystal lattice structure of the ionic compound.

**Answers to Questions in the Student Worksheet**

1. Select Calcium as the metal and Oxygen as the nonmetal. Explain the electron transfer between calcium and oxygen to form the ionic compound calcium oxide.

   **Answer:** A calcium atom loses two electrons and an oxygen atom gains these electrons to form an ionic compound called calcium oxide.

2. Select Calcium as the metal and Nitrogen as the nonmetal. Can you form an ionic bond between them? Analyze and explain how this is related to their difference in electronegativity.

   **Answer:** The difference in electronegativity between calcium and nitrogen is more than 1.7. Therefore, an ionic bond can be formed between them. Three atoms of calcium lose two electrons each and two atoms of nitrogen gain three electrons each to form calcium nitride.

3. Select Magnesium as the metal and Sulfur as the nonmetal. Transfer electrons to build the ionic compound magnesium sulfide and then identify each ion’s name and charge.

   **Answer:** One atom of magnesium loses two electrons to form a positively charged magnesium ion. One atom of sulfur gains those electrons to form a negatively charged sulfide ion.

4. Select Potassium as the metal and Nitrogen as the nonmetal. Identify the ionic compound that can form between them.

   **Answer:** Three atoms of potassium lose one electron each and one atom of nitrogen gains those electrons to form potassium nitride.
5. Write down the reaction for the ionic bond formed between sodium and fluorine.

**Answer:** One atom of sodium loses one electron and one atom of fluorine gains that electron to form sodium fluoride.

\[ \text{Na}^+ + \text{F}^- \rightarrow \text{NaF} \]

6. Compare the crystal lattice structures of the ionic compounds calcium chloride and potassium sulfide.

**Answer:** Calcium chloride has an orthorhombic crystal lattice structure whereas potassium sulfide has an antifluorite crystal lattice structure.

7. What kind of crystal lattice structure is formed when lithium and fluorine combine to form lithium fluoride?

**Answer:** A cubic crystal lattice structure is formed when lithium and fluorine combine to form lithium fluoride.

8. Explain why noble gases cannot participate in ionic bond formation.

**Answer:** Noble gases have fully filled electron shells. They do not have any valence electrons. Thus, they do not participate in ionic bond formation.

9. Differentiate between atoms and their ions on the basis of their stability.

**Answer:** Atoms have unstable electron configurations because they do not have a completely filled outermost shell. They lose or gain electrons to attain a stable outer shell, and therefore form ions. Thus, ions have more stable electron configurations than atoms.

10. After building compounds in the Exploration, use the information you have learned to write the correct compound formula for aluminum chloride and aluminum phosphide.

**Answer:** Aluminum chloride: AlCl₃
Aluminum phosphide: AlP
Data/Graph Tool

Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
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- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
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Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
English Language Proficiency Activity

Concept: Covalent Bonding

Overview: You will watch a video segment and work with a partner to summarize the information from the video.

Directions:

1. Watch the video segment "Covalent Bonds" with closed captioning.
2. Talk to a partner and tell him or her about the information from the video.
3. Watch the video again and write down any information you missed.

What parts of Techbook are you using? ________________________________

Who are you working with?

the whole class     a group     one other person     nobody

What will you have when you finish? ________________________________

Words to Know: Add key words and a picture or example to help you remember each word.

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>covalent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bond</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Write a few short sentences about what you saw in the video. Use the questions words to help you.

- What?______________________________________________________________
- Where?_____________________________________________________________
- How?_______________________________________________________________

Is there anything you don’t understand? Is there anything you want help with?
Hands-On Lab
Toying with Bonds

Timing: one 90-minute class session

Objective
In this lab, students will observe the change in properties of a material as the number of covalent bonds between molecules increases. Students will then plan a procedure to vary the reactants in a systematic way in order to collect observations of the material’s properties. Students will suggest the appropriate amounts of reactants to use based on their observations and the final properties desired.

Safety Precautions
Inform students that some people have an allergic reaction to sodium borate. Remind students to wear gloves, goggles, and closed-toed shoes throughout the lab. Remind them not to eat or drink anything in the lab (including the experimental materials). Tell students to report any broken glass and not to try and clean it up themselves.

Materials
Per student:
- gloves
- goggles
- lab apron

Per group:
- (1) 100 mL diluted white glue
- (1) 100 mL 4% sodium borate solution
- (2) plastic spoon
- (2) plastic cup
- (1) wooden stir stick

Teacher Preparation
- Prepare the glue solution ahead of time by diluting 50 mL of white glue with an equal volume of distilled water for each group.
- Prepare a copy of the Student Investigation sheet for each student.

Procedure
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.
You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Demonstrate for students how to combine and mix the reactants to form the product.

One possible procedure:
1. Show students the glue solution and the sodium borate solution. Ask students to describe properties of each one.
2. Add 2 spoonfuls (about 10 mL) of glue solution to a plastic cup.
3. Add 2 spoonfuls (about 10 mL) of sodium borate solution to the plastic cup.
4. Stir the mixture with the wooden stir stick. Have students describe how the properties of the material are changing.
5. Knead the material with your hands. Demonstrate how the material responds to being squeezed, pulled, and dropped.
6. Divide students into groups of 2–3 students and proceed to the Guided Inquiry.

**Guided Inquiry**
Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- What will be kept constant in the experiment?
- What will be the variables in the experiment?
- What properties do you expect the product to have?

Tell students to imagine that they are research scientists working for a toy manufacturer. Their job is to develop a new product from glue and sodium borate. They will need to submit their research plan to you for approval before they begin collecting data because only five trials are permitted. Their plan should include the properties of the desired product, the amounts of materials needed, a step-by-step procedure, and a data collection table. After you have approved a group’s plan, instruct the group to implement its plan to begin collecting data.
Each pair of students should develop a research plan that includes the following:

- identification of the constant and the variable
- amounts for at least five trials (Students might choose to plan four trials and to perform the fifth as a way to fine-tune the amounts for the product recommendation.)
- the desired properties of the product

Sample data table:

<table>
<thead>
<tr>
<th>Amount of Glue solution (mL)</th>
<th>Amount of Sodium borate solution (mL)</th>
<th>Observed properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Analysis and Conclusions

Use the questions below to help your students analyze and interpret their results, discuss the following questions, or assign them as homework:

1. Based on your data, write up your recommendation to the toy company. Include the goal of your research and the criteria and scoring you used to evaluate the different glue mixtures. Present these criteria and the accompanying scoring system in a table format. Write a paragraph defending your conclusion.

*Sample answer: Answers will vary depending on the criteria students identify and the scoring tool they use, but should show a set of evaluation criteria and a valid scoring rubric for their observations. Criteria could include such properties as stickiness, drying time, ease of handling. They should provide an evaluation of these properties to support their recommendation to the toy manufacturer.*

2. After the toy goes into production, you receive an urgent message from the plant manager saying that there is a problem in manufacturing and the product is coming out too runny. Write a reply to identify the likely problem and offer two possible solutions.

*Sample answer: The proportion of sodium borate to glue is too low. Increase the amount of sodium borate or decrease the amount of glue to fix the problem. The glue was diluted with too much water. Make sure the glue and water are mixed in equal proportions.*

3. Compare your product with those of other groups. Explain any differences or similarities in the results.

*Sample answer: Groups that wanted the same type of properties for the product had results similar to ours. But in groups that wanted different properties, the relative amounts of glue and sodium borate were reversed from our recommendation.*

4. Explain the properties of the product you created as they relate to covalent bonding.

*Sample answer: The sodium borate helped to increase the number of covalent bonds in the product. The product became firmer and more solid as more covalent bonds formed in the material.*
Inquiry and Nature of Science Skills in this Lab

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Study: compares changes in data points over time
  - Design and conduct investigations using:
    - Independent variable: the one variable the investigator chooses to change
    - Dependent variables: what changes as a result of, or in response to, the change in the independent variable
    - Constant: identify variables that must remain unchanged
    - Multiple trials: repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Choose appropriate tools to conduct an investigation:
    - Graduated cylinder
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Touching (temperature, texture, shape, size, vibration, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated
• Communication in Science
  o Report results using
    ▪ Written report
    ▪ Scientific explanations/arguments
    ▪ Table/graph showing data

• Patterns and Systems
  o Patterns and Change:
    ▪ Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    ▪ Things that change may do so in steady, repetitive or irregular ways.

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ Science takes place in many locations including labs, offices, fields, and under the ocean.
    ▪ Scientific investigation results in things we know and things we don't know.
  o Scientific Data and Outcomes:
    ▪ Collecting and analyzing data is the best way to understand a changing pattern.
    ▪ It is important in science to keep honest, clear, and accurate records.
Data/Graph Tool
Teacher’s Guide

Introduction

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Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

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Hands-On Activity
Introduction to Molecular Geometry

Objectives:
Observe a force that is related to molecular geometry.
Demonstrate underlying principles of molecular geometry.
Form questions about effects of molecular geometry.

Estimated time to complete: 30 minutes

Materials:
For each pair of students
• Clear plastic tape (two lengths, 30 cm each)
• One carbon atom (ball with four holes) and four bonds (sticks) from a molecular model kit

Procedure:
Note: These activities could be completed in a variety of ways. A teacher demonstration of each activity could be used to support class discussion. Small groups or pairs could conduct the activities, as suggested here. Or each activity could be set up at a separate station as students cycle through them.

1. Electrostatic repulsion.
Ask the students to stick two 30 cm pieces of tape to a smooth, clean surface. Pull both pieces of tape up quickly. Instruct the students to hold the tape strips vertically and parallel and bring them slowly together. Have them try this with both the sticky and non-sticky sides facing each other.

Ask if anyone recalls a principle that explains the repulsion of the tape strips. Discuss the answers, and then explain that the tape picked up electrons from the surface, making both strips negatively charged. Review the principle that like charges repel and unlike charges attract.

2. Tetrahedral geometry.
Show the students the tetrahedron. Ask them to examine the ball that represents the carbon atom. Ask if anyone sees a connection between the ball and the tetrahedron. Instruct students to insert the sticks (bonds) into the ball (atom). Discuss the angles between the sticks and explain that the importance will become clear later in the sessions that explore this concept.

3. Unique properties of water.
Drop an ice cube into a beaker of water. Ask if there is anything unusual about the fact that it floats. Ask what will happen when a wax cube is dropped into the liquid wax. Drop the cube of wax into the liquid wax. Lead the class in a discussion of their observations about the differences in the behavior of wax and water. Ask which material is behaving in an unusual way and why. Explain briefly, in terms of kinetic molecular theory, why wax behaves as would be expected and water does not.
Summary:
Ask the students to write a summary in their notebooks describing what they observed and listing any unanswered questions. Explain that future sessions will reveal the importance of these three demonstrations. Explain that the behavior of the tape in the first activity helps explain the arrangement of the bonds in the second activity. Explain that the arrangement of the bonds in the second activity helps explain the behavior of ice and water in the third activity.
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated.

- **Gather Data**
  - Use senses to observe:
    - Touching (temperature, texture, shape, size, vibration, motion)

- **Gather Data**
  - Uses the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Sorts and classifies using scientific reasoning:
    - Objects, substances and organisms by characteristic
Overview

Lewis structures help us to understand the molecular geometry of compounds. In this Exploration, students learn about the formation of covalent compounds by creating their Lewis structures. They also observe the molecular geometry of the created compounds.

Student Learning Objectives

- Investigate Lewis structures of covalent compounds.
- Examine the Lewis structures of compounds using the electron dot model.
- Observe the molecular geometry of compounds with reference to their bond angle and molecular shape.
- Understand the relation between electronegativity of elements and their ability to form covalent compounds.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students create the Lewis structures of covalent compounds by dragging valence electrons and bonds around the symbols of selected elements. Students use the Select Element dropdown lists to choose elements to build compounds with. The Add button is used to add the symbols of these elements to the grid. The symbols may be dragged around the grid and additional instances of the elements may be added using the Add button. The Remove button is used to delete an instance of the element symbol.

Valence Electrons and Bonds may be dragged around the symbols to create the Lewis structure of a compound. To create double or triple bonds, multiple bonds may be dropped into the slots around the element symbols. Clicking on the Show Electronegativity checkbox shows the students the difference in electronegativity between the two selected elements.

Students use the Check button to validate their structures. If the Lewis structure is correctly created, the View Animation button is clicked to observe the molecular geometry of the compound formed. The Reset button may be used at any point in the Exploration to begin creating a new Lewis structure. Students may also use the Demo button to see a short tutorial on creating the Lewis structures of compounds exhibiting single, double, and triple bonds.

Students track and compare the compounds formed using the Tracker tab. The various columns in the Tracker tab show the successfully formed compounds with their constituent
elements, number of bonding pairs of electrons, number of lone pairs of electrons, molecular structure, shape, bond angle, and electronegativity difference. Students may click on the button in the Molecular Structure column to observe the geometry of the compounds formed.

**Answers to Questions in the Student Worksheet**

1. Lewis structures are also known as electron dot diagrams. State the reason for this.

   **Answer:** Lewis structures are known as electron dot diagrams since the electrons in Lewis structures are represented by dots. The bonds are represented by dashes.

2. Name the commonly observed molecular geometries of molecules along with their bond angles.

   **Answer:** The most common molecular geometries are the linear (180°), trigonal (120°) and tetrahedral (109.5°) geometries. Trigonal compounds can either be trigonal planar or trigonal pyramidal, depending on whether the constituent atoms lie in one plane or not.

3. Explain why ionic bonds cannot be represented by Lewis structures.

   **Answer:** In Lewis structures, a bonding pair of electrons is represented by a pair of dots. This bonding pair of electrons is shared in covalent compounds. On the other hand, ionic compounds are formed by donation and acceptance of electrons, which cannot be represented by bonding pairs of electrons. This is why ionic bonds cannot be represented by Lewis structures.

4. Describe how lone pairs of electrons contribute to the shape of a molecule.

   **Answer:** Lone pairs of electrons are repelled by other electrons, including bonding pairs of electrons, due to their negative charges. These repulsive forces cause the bond angles of compounds exhibiting lone pairs of electrons to be greater than usual. These increased bond angles contribute to differences in shape between molecules that have lone pairs of electrons.

5. Explain the significance of electronegativity in formation of compounds.

   **Answer:** The difference in electronegativity of the constituent elements of most covalent compounds is less than 1.7 Pauling units. For constituent elements of ionic compounds, this difference is greater than 1.7 Pauling units.
6. Give two examples of compounds that exhibit a tetrahedral molecular geometry.
   
   **Answer:** Methane and carbon tetrachloride are characterized by a tetrahedral molecular geometry.

7. Explain why the bond angle in water is 105°.
   
   **Answer:** A water molecule has two lone pairs of electrons that belong to the oxygen atom. The repulsive forces between these lone pairs of electrons lead to a decrease in bond angle from 109° to 105°.

8. Draw the Lewis structure of beryllium fluoride.
   
   **Answer:**
   
   ![F—Be—F](image)

9. A covalent compound has a bond angle of 180°. Name the shape that its molecule exhibits.
   
   **Answer:** If the molecule of a covalent compound has a bond angle of 180°, then its molecular shape is linear.

10. One way of representing bonding pairs of electrons is shown in the Exploration. State the other method that is commonly used to represent bonding pairs of electrons.
    
    **Answer:** In the Exploration, bonding pairs of electrons are represented by dashes. Alternatively, a pair of dots can represent such bonds.
**Hands-On Activity**
**Surface Tension of Water**

**Objective:**
Demonstrate surface tension of liquid water

**Estimated time to complete:** 5 minutes

**Materials:**
For each pair of students
- One small beaker of water (20 mL)
- One 1-inch square of aluminum foil

**Procedure:**
Have students work in pairs. Each pair will have a small beaker partially filled with water and a one-inch square of aluminum foil.

1. Tell the students that the density of aluminum is 2.7 g/mL, and the density of water is 1.0 g/mL. Ask them what will happen if the aluminum square is placed on the surface of the water.

2. Inquiry Alert: This is an excellent activity for students to explore how changing the shape of the aluminum will change their results. Have the students carefully place the aluminum on the water and observe the result. Ask for ideas about why the aluminum does not sink. Ask them to predict what will happen if the aluminum square is pushed to the bottom of the beaker.

3. Have the students push the aluminum to the bottom of the beaker and observe the result.

4. Ask for responses to these questions:
   a. Did the aluminum ever actually float?
   b. If not, what held it up?
   c. Why did the aluminum remain on the bottom?
   d. Would an aluminum ball the size of a marble have stayed on the surface? Why or why not?

**Summary:**
Surface tension caused the aluminum to appear to float. Greater density caused the aluminum to remain on the bottom when it was pushed down. The force of gravity on a solid aluminum ball would be strong enough to overcome the surface tension.
Inquiry and Nature of Science Skills in this Activity:

- Identify Questions
  - Develop predictions/hypotheses that:
    - state the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Gather Data
  - Use senses to observe:
    - Touching (temperature, texture, shape, size, vibration, motion)

- Interpret Data
  - Sorts and classifies using scientific reasoning:
    - Objects, substances and organisms by characteristic

- Evaluate Evidence
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause effect relationship observed in the investigation
    - Comparing results to hypothesis

- Scientific Investigation
  - Scientific Investigation
    - Science investigation begins with a testable question.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
Hands-On Lab
VSEPR and Molecular Shapes

Timing: one 90-minute class session

Objective(s):
In this activity, students will use balloons to build models of the arrangement of electrons around a central atom in a molecule. The students will use these models to examine the shapes and bond angles of molecules that have up to four sets of electrons around the central atom. The students will examine the effect of non-bonding electron pairs on bond angles and relate the Lewis structures of molecules to the appropriate balloon model.

Safety Precautions:
Students should wear safety goggles in case any balloons pop. Students who have latex allergies should not handle the balloons unless non-latex balloons are available.

Materials:
Per pair or group:
- 4 round balloons, 5”
- 2 round balloons, 9”
- Protractor
- Goggles

Teacher Preparation
Inflate a set of balloons to use as a demonstration set. You may wish to inflate a set of balloons for each group to reduce the chance of overinflation and the time required to perform the activity.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’
activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Demonstrate for students how to use the balloons to represent sets of electrons around a central atom.

1. Hold the necks of two inflated 5" balloons between your fingers so that the balloons are pulled tightly to one another. Your fingers represent the central atom, and each balloon represents a set of electrons.
2. Push one balloon close to the other, and then release it. Observe that the balloons push each other away and adopt a linear orientation.
3. Draw a sketch of your model. Use the protractor to identify and record the angle between the balloons.
4. Add an additional 5" balloon. Examine the orientation of the three balloons. Draw a sketch of your model. Identify the angle between each pair of adjacent balloons.
5. Replace one of the balloons with an inflated 9" balloon to represent a non-bonding pair of electrons. Record the change that occurs to the angle between the smaller balloons.
6. Draw Lewis structures of the following molecules: BH$_3$, CO$_2$, and O$_3$. Match each molecule with one of the models. Predict the expected bond angle in each molecule.

Instruct students to design and write a procedure to continue the modeling exercise by creating three different models using four balloons, beginning with four 5" balloons. Remind students that the angle that results when they use four 5" balloons is 109.28°. Have students compare their sketches with those of other groups.

When they have completed their models, have each group draw Lewis structures for the following molecules: CH$_4$, PH$_3$, NF$_3$, H$_2$O, CF$_4$, and SCl$_2$. Then, have students match each molecule with one of their models. Models may correspond to more than one molecule.

**Guided Inquiry**
Distribute the supplies to pairs or small groups. Have students create a demonstration that shows the relationship between the number of electron pairs present and bond angles. You might choose to have students share their demonstrations or write a summary of them.

Next, instruct students to design and write a procedure to continue the modeling exercise by creating three different models using four balloons, beginning with four 5" balloons. Remind students that the angle that results when they use four 5" balloons is 109.28°. Have students compare their sketches with those of other groups.

When they have completed their models, have each group draw Lewis structures for the following
molecules: CH₄, PH₃, NF₃, H₂O, CF₄, and SCl₂. Then, have students match each molecule with one of their models. Models may correspond to more than one molecule.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Why does the number of sets of electrons around the central atom determine the shape of the molecule? *Each set of electrons repels the others. The shape of the molecule is determined by how far apart the sets can get from each other.*

2. What happens to the bond angle as the number of non-bonding pairs of electrons increases? *The bond angle decreases with each additional non-bonding pair.*

3. How do the numbers of atoms bonded to the central atom and the numbers of non-bonding pairs on the central atom compare in water and carbon dioxide? *Both water and carbon dioxide molecules have two atoms bonded to the central atom. Water has two non-bonding pairs on its central atom, but carbon dioxide has none.*

4. A carbon dioxide molecule is nonpolar. When can a linear molecule made up of three atoms be polar? *If the atoms bonded to the central atom differ from each other and at least one of the bonds is polar covalent, the molecule will be polar.*

5. Water molecules and carbon dioxide molecules are each composed of three atoms and have bonds that are polar covalent. However, these substances exist in different states at room temperature and atmospheric pressure. How do the shapes of their molecules help to explain this difference? *Water is a liquid at room temperature and atmospheric pressure. Carbon dioxide is a gas at room temperature and atmospheric pressure. Water molecules are polar and have a bent shape because of the unbonded pair of electrons on the oxygen atom. Water molecules have stronger attractions to other water molecules because of their polarity than the linear, nonpolar carbon dioxide molecules. The forces among water molecules cause water to be in the liquid state at room temperature.*
Inquiry and Nature of Science Skills in this Lab:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated.
    - Are based on logic and evidence.
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation.
  - Practice lab safety by:
    - Following lab safety procedures.

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record data:
    - Sketch

- **Interpret Data**
  - Identifies and interprets patterns:
    - Based on an analysis of data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Formulating scientific explanations/arguments.

- **Communication in Science**
  - Report results using:
    - Written report
    - Scientific illustration with proper labeling
    - Images or video
    - Formulating scientific explanations/arguments

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating a conclusion
    - Analyze scientific explanations
Exploration Teacher Guide: Chemical Formulas

Overview

In this Exploration, students build chemical formulas for binary and polyatomic compounds. Students can also examine how the oxidation states of ions are related to the number of atoms in the compound’s elements.

Student Learning Objectives

- Understand the difference in the chemical formulas of binary and polyatomic compounds.
- Investigate the relationship between oxidation states of ions and the number of atoms in a chemical compound’s elements.
- Determine the equation that represents the overall charge of the chemical formula.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students select a compound using options in the Select Compound dropdown list. Students drag and drop items from the Elements, Oxidation Number, and Number of Atoms sections to build the compound’s chemical formula.

An equation that represents the overall charge of the formula is displayed. As the student provides the correct number of atoms and oxidation number the equation is completed, encourage students to use this equation as a hint, as the overall charge of the formula should be zero.

Students may use the View Demo button to learn how to build a chemical formula in this Exploration. They can use the Reset button to begin over with the selected compound or to select another compound.

The Tracker tab allows students to compare the symbols and oxidation states of the constituent elements of compounds they create. The Tracker also displays the chemical formula and type of each compound.

Answers to Questions in Student Worksheet

1. Explain the term binary and polyatomic compounds with an example.

   Answer: Binary compounds are compounds made of two elements. Water (H₂O) is an example of a binary compound as it is made of two elements, hydrogen and oxygen.
2. Explain the role of oxidation number in determining the subscript of an element in a chemical formula.

**Answer:** The subscript of an element in a chemical formula represents its number of atoms. In a chemical formula, the oxidation number of an element determines the number of atoms needed to form a stable compound with another element.

3. Explain how a chemical formula is built for a compound that has a polyatomic ion bonded with a metal. Give an example.

**Answer:** The chemical formula of a compound that has a polyatomic ion bonded with a metal is built by placing the polyatomic ion inside the parenthesis. A subscript outside the parenthesis is used to indicate the number of the polyatomic ions needed to form a compound with the metal. Calcium hydroxide is a compound that comprises of calcium and hydroxide ion. The oxidation number of calcium is +2 and that of the hydroxide ion is -1. The chemical formula is written as Ca(OH)$_2$.

4. Use the Exploration to build the chemical formulas for the following compounds. Indicate the compound’s constituent elements, the elements’ number of atoms and oxidation number, and whether the compound is binary or polyatomic.

   a. Tin (IV) iodide
   b. Cesium nitride
   c. Silver permanganate
   d. Cadmium chromate

**Answer:**

a. Tin (IV) iodide is a binary compound comprising tin and iodine. The oxidation number of tin is +4 and that of iodine is -1. One atom of tin needs four atoms of iodine to form a molecule of tin (IV) iodide. Hence, the chemical formula of tin (IV) iodide is SnI$_4$.

b. Cesium nitride a binary compound comprising cesium and nitrogen. The oxidation number of cesium is +1 and that of nitrogen is -3. One atom of nitrogen needs three atoms of nitrogen to form a molecule of cesium nitride. Hence, the chemical formula of cesium nitride is Cs$_3$N.

c. Silver permanganate is a polyatomic compound comprising silver and a permanganate ion. The permanganate ion comprises manganese with oxidation number +7 and oxygen with oxidation number -2. The overall oxidation number of the permanganate ion is -1 and can be represented as MnO$_4$.$^{-1}$. The oxidation number of silver is +1. One atom of silver needs one permanganate ion to form a molecule of silver permanganate. Hence, the chemical formula silver permanganate is AgMnO$_4$.

d. Cadmium chromate is a polyatomic compound comprising cadmium and chromate. The chromate ion comprises of 1 atom of chromium with oxidation number +6 and oxygen with oxidation number -2. The overall oxidation number of the chromate ion is -1. Chromate can be represented as CrO$_4$.$^{2-}$. The oxidation number of cadmium is +2. One atom of cadmium needs one chromate ion to form a molecule of chromium chromate. Hence, the chemical formula cadmium chromate is CdCrO$_4$. 

5. Build the chemical formulas for binary compounds that are formed with the following pair of elements.
   a. Zinc and selenium
   b. Silver and oxygen
   c. Potassium and phosphorus
   d. Calcium and iodine

Answer:
   a. Zinc and selenium combine to form zinc selenide. The oxidation number of zinc is +2 and that of selenium is -2. One atom of zinc combines with one atom of selenium to form zinc selenide and its chemical formula is ZnSe.
   b. Silver and oxygen combine to form silver oxide. The oxidation number of silver is +1 and that of oxygen is -2. Two atoms of silver combine with one atom of oxygen to form silver oxide and its chemical formula is Ag₂O.
   c. Potassium and phosphorus combine to form potassium phosphide. The oxidation number of potassium is +1 and that of phosphorus is +3. Three atoms of potassium combine with one atom of phosphorus to form potassium phosphide and its chemical formula is K₃I.
   d. Calcium and iodine combine to form calcium iodide. The oxidation number of calcium is +2 and that of iodine is -1. One atom of calcium combines with two atoms of iodine to form calcium iodide and its chemical formula is CaI₂.

6. Classify the following compounds as binary or polyatomic compounds.
   a. Ammonium hydroxide
   b. Magnesium chloride
   c. Copper oxide
   d. Lithium chlorate

Answer:
   a. Ammonium hydroxide comprises of ammonium ion (NH₄⁺) and hydroxide ion (OH⁻). Since it comprises of more than two atoms, it is a polyatomic compound.
   b. Magnesium chloride comprises of magnesium (Mg) and chlorine (Cl). Since it comprises of two atoms only, it is a binary compound.
   c. Copper oxide comprises of copper (Cu) and oxygen (O). Since it comprises of two atoms only, it is a binary compound.
   d. Lithium chlorate comprises of lithium (Li), chlorine (Cl) and oxygen (O). Since it comprises of more than two atoms, it is a polyatomic compound.

7. In the Exploration, select aluminum sulfide. Add the two elements and then add 2 as the number of atoms for sulphur. Observe what happens and explain the reason for your observation.

Answer: Aluminum sulphide is made up of aluminum and sulphur. As the oxidation number of aluminum is +3, it takes 3 atoms of sulphur to form aluminum sulfide. Since the number of atoms of sulphur is not 2, this number cannot be added to the chemical formula of aluminum sulfide.
8. Iron and oxygen combine to give either ferrous oxide or ferric oxide. Build the chemical formulas of the two compounds. Explain your reasoning.

**Answer:** Ferrous oxide and ferric oxide both comprise of iron and oxygen. The oxidation number of iron is +2 in ferrous oxide and +3 in ferric oxide. The oxidation number of oxygen is -2 in ferrous oxide and ferric oxide. One atom of iron needs one atom of oxygen to form ferrous oxide while two atoms of iron need three atoms of oxygen to form ferric oxide. Hence, the chemical formula for ferrous oxide and ferric oxide can be written as FeO and Fe$_2$O$_3$.

9. Compounds can be represented using their chemical formulas. State two other types of formulas that can represent a compound. Give examples.

**Answer:** Apart from chemical formulas, compounds can also be represented using the empirical formula and the Lewis structure. An empirical formula of a compound is the simplest whole number ratio of atoms of each element present in a compound. For example, the empirical formula of iso-octane is C$_4$H$_9$. The Lewis structure is a graphical way of representing a chemical compound in which the electrons of the inner closed shells is represented by the element symbol, valence electrons and the bonded pair of electrons by a dash. For example, the Lewis structure for hydrochloric acid can be given as:

\[
\text{H--Cl}^+ 
\]

10. Compare the oxidation state of an element in its free state with that in its ionic state with an example.

**Answer:** The oxidation state of an element in its free state is equal to zero. For example, the oxidation state of hydrogen in its free state is equal to zero. The oxidation state of an element in its ionic state is equal to the charge of its ion. For example, the oxidation state of hydrogen in its ionic state is equal to the charge of its ion which is +1.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.
- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Ionic Rummy

Timing: one 90-minute class session

Objective(s):
In this activity, students will be challenged to construct ionic compounds given a random selection of ions, their identity, and their charge. The format for the activity will be a card game similar to “500 Rummy.” Thus, students will compete to form the largest number of ionic compounds and will earn points related to the complexity of the compounds.

Safety Precautions:
No safety concerns.

Materials:
Per pair or group of three students:
- deck of 52 “ion cards”
- “Rules of Ionic Rummy”
- pencil and score sheet

Teacher Preparation:
- Each deck of “ion cards” should consist of 52 cards on which you have printed the symbols and charge for various ions. Note: For additional challenge, you might want to prepare a set of cards that do not show the charges of the ions.
- There should be 26 cation cards and 26 anion cards.
- The distribution of cards should be the following: 10 Na⁺, 8 Ca²⁺, 8 Al³⁺, 10 Cl⁻, 8 SO₄²⁻, and 8 PO₄³⁻.
- You can use a computer to produce the cards from sheets of 2 ¼” x 3 ½” name badge insert refills for laser or ink jet printers, obtainable from any major office supply store.
- Prepare copies of Ionic Rummy rules for each group.
- Prepare a copy of the Student Investigation Sheet for each student.
- Estimated Time for Preparation: 25 minutes

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative
process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
Tell students that to get more practice with chemical formulas, they will play a card game called Ionic Rummy. Give each group a copy of the rules, and run through the rules and procedures of the game with the class.

Rules of Ionic Rummy:
- Each student is dealt 7 cards.
- The deck is placed face down in the center of the table.
- In turn, players draw a card from the deck and discard a card face up next to the deck.
- The next player may pick up the discarded card or pick a card from the deck.
- After each turn, a player should lay out, face up, combinations of cards that produce an ionic compound. These will be combinations of 2-5 cards, as described in the scoring system below.
- The other player(s) may challenge the accuracy of the compound. If the challenge is upheld (after consultation with the teacher), the challenged student loses 5 points and the challenging player gains 5 points, provided the challenger can correctly explain the error. Otherwise, the challenged student loses 5 points, but the challenger gains no points. The challenged student returns the cards for the incorrect compound to his or her hand, and play continues.
- Play continues until one player plays the last card in his or her hand. Values for the compounds that have been laid down by each player are tallied and recorded on a score sheet.
- The first player to reach 500 points wins the game. NOTE: Due to time considerations, consider other winning scores, such as 100, 150, or 200 points.
- Scoring System
  2-ion combination: 2 points
  3-ion combination: 3 points
  4-ion combination: 4 points
  5-ion combination: 5 points
Examples of combinations at each point value:

2-ion combination: NaCl, CaSO₄, AlPO₄
3-ion combination: Na₂SO₄, CaCl₂
4-ion combination: Na₃PO₄, AlCl₃
5-ion combination: Ca₃(PO₄)₂, Al₂(SO₄)₃

Guided Inquiry

Students can design variations on Ionic Rummy, using different ions, different rules, and different scoring methods. Ask the students some guiding questions to help them focus their inquiry:

- How could you change the rules of the game?
- Which ions would you add to or remove from the deck?
- Would you modify the scoring system? If so, how?
- Would you change the structure of the game, say, from a card game to a board game?

Have students present their modifications or new designs to you for critical review. Make sure students provide an educational rationale that is supported by the game. Although the game should be fun to play, it should be an effective teaching tool. You may wish to suggest that students should consider incorporating various kinds of media in their designs, such as computers and overhead projectors. For example, the “finals” of a tournament might be projected on a screen for class observation and discussion as play progresses. The class might act as arbiters of challenges.

As a variation of Ionic Rummy, you may ask students to invent an Empirical Formulas game in which students score points by producing empirical formulas from a variety of molecular formulas. The format for the game can be determined by students, but should meet the fundamental criteria for Ionic Rummy. That is, the new game should be both fun and educational.

Analysis and Conclusions:

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What is the educational purpose of the game? Sample response: To discover the factors that influence the ratio of ions in an ionic compound.

2. How does charge affect the ratio of ions in an ionic compound? The ratio of ions must be such that the overall charge of the compound is zero. In other words, the number of negative charges must equal the number of positive charges.

3. What is the significance of symbols and implied subscripts in the construction of ionic compounds in the game? The implied subscripts indicate the number of each ion in each constructed compound. The symbols indicate the identity of the elements in each compound.
Inquiry and Nature of Science Skills in this Lab:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
    - Apply mathematical operations and principles to replicate the real thing.
    - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
  - Use the appropriate format to record data:
    - Chart

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances, and organisms by characteristic
    - Applying a classification scheme to objects, substances, or organisms

- **Communication in Science**
  - Report results using:
    - Written report

- **Patterns and Systems**
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Many patterns in nature contain symmetry.
    - Symmetry in patterns is a result of natural balance and counteraction.
    - Symmetry may determine properties of many objects, such as molecules, crystals, organisms, and designed structures.
    - Mathematical patterns help to predict future events and describe change in systems.

- **Scientific Investigation**
  - Scientific Investigation:
    - Scientific investigation results in things we know and things we don't know.

- **Scientific Endeavor**
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Hands-On Activity
Working with Chemical Names

Objective:
Students will explore the function of chemical formulas in real-life applications.

Estimated time to complete: 10 minutes

Materials:
For each small group:
- a product label showing a list of ingredients that includes complex chemical names

Procedure:
Have students look through the list of ingredients. Ask, What do you notice about many of these names? (The names are long and complex.) Ask, Why are the names so complex? (They must include information about the specific composition and structures of the chemicals used in the product.)

Have students try to come up with their own shorthand methods for listing the chemical names. They will likely already have had some experience with chemical symbols and formulas, so you might want to suggest that they try to invent a new method that reliably conveys information about the composition and structure of a compound.

After a few minutes, have all groups share their ideas. As a class, discuss the pros and cons of each method of representing the ingredients.
Inquiry and Nature of Science Skills in this Activity:

- Identify Questions
  - Develop a question that:
    - asks a question about a specific science concept or process
- Scientific Endeavor
  - Historical Perspectives:
    - Important contributions to the advancement of science, mathematics, and technology that have been made by different kinds of people, in different cultures, at different times.
High School Explorations

Exploration Teacher Guide: Chemical Reactions and Equations

Overview

A chemical reaction is a chemical change in which a substance changes from one form to another. In this Exploration, students identify the products that will form in different chemical reactions and balance the equations of these reactions.

Student Learning Objectives

- Examine the various types of reactions through which elements and compounds react.
- Identify the product for a given set of reactants.
- Observe how chemical equations are balanced to represent chemical reactions.
- Verify that the volume of the constituents of the products is equal to that of the reactants.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students select a type of reaction using options in the Select Reaction dropdown list. They observe the reactants in the Reactants section and then select the product for this reaction using options in the Select Product dropdown list. Students use the Check button to validate the selected product.

Students balance the chemical equation by increasing or decreasing the number of moles for each reactant and product using the spin box. They can add up to 3 moles for each reactant and product. As the values are changed in front of each unit, the bar graph below gets updated. Students use the Balance button to validate if they have balanced the equation correctly. Students use the Show Me! button to view the correct balanced equation.

In the Tracker tab, students track the chemical equations that they have balanced correctly for different types of chemical reactions. They also observe the number of moles of each reactant and product.
Answers to Questions in the Student Worksheet

1. Predict the products for the following chemical reactions and balance the equation.

   a. ____ Hg_2Br_2 + ____ Cl_2 →
   b. ____ (NH_4)_3PO_4 + ____ CaCl_2 →

   Answer:
   a. Hg_2Br_2 + 2Cl_2 → 2HgCl_2 + Br_2
   b. 2(NH_4)_3PO_4 + 3CaCl_2 → Ca_3(PO_4)_2 + 6NH_4Cl

2. Identify the chemical reaction when:

   a. two or more simple compounds of reactants combine to form a complex compound.
   b. a complex compound breaks down to form two or more simple compounds of products.

   Answer:
   a. Synthesis.
   b. Decomposition.

3. Define mole.

   Answer: A mole is the amount of substance that contains $6.023 \times 10^{23}$ molecules. A mole of carbon-12 weighs 0.012 kg.

4. Write the word equations for the following balanced chemical equations.

   a. Zn + 2HCl → ZnCl_2 + H_2
   b. 2SO_3 → 2SO_2 + O_2

   Answer:
   a. One atom of zinc reacts with two molecules of hydrochloric acid to form one molecule of zinc chloride and one molecule of hydrogen.
   b. Two molecules of sulfur trioxide decompose to form two molecules of sulfur dioxide and one molecule of oxygen.
5. State the law of conservation of matter. Explain how a balanced chemical equation demonstrates the law of conservation of matter.

**Answer:** The law of conservation of matter states that matter can neither be created nor destroyed.

In a balanced chemical equation, the numbers and types of atoms present in the products is equal to the number of atoms present in the reactants which demonstrates law of conservation of matter. For example, the balanced chemical equation of the reaction of hydrogen with oxygen to produce water can be given as:

\[
2H_2 + O_2 \rightarrow 2H_2O
\]

The number of atoms of both hydrogen and oxygen in the products is equal to the number of atoms both hydrogen and oxygen present in the reactants.

6. Compare and contrast single displacement and double displacement reactions.

**Answer:** All single displacement reactions have the general form, \( A + BC \rightarrow B + AC \). On the other hand, double displacement reactions have the general form, \( AB + CD \rightarrow AD + CB \). Reactions that can be classified as double displacements include precipitation reactions, neutralization reactions, and gas forming reactions.

7. Describe a combustion reaction.

**Answer:** Combustion occurs when oxygen as a reactant combines with a compound of another reactant to form water and carbon dioxide as products. It releases heat which makes it an exothermic reaction.

8. Write down the generalized equation of a synthesis reaction.

**Answer:** The generalized equation of a synthesis reaction is \( A + B \rightarrow AB \). This is also known as an addition reaction.

9. Use this Exploration to identify the products formed from the double displacement reaction of sodium carbonate (\( Na_2CO_3 \)) and calcium hydroxide (\( Ca(OH)_2 \)). Write the balanced chemical equation for the same.

**Answer:** Sodium hydroxide (\( NaOH \)) and calcium carbonate (\( CaCO_3 \)) are formed from the double displacement reaction of sodium carbonate (\( Na_2CO_3 \)) and calcium hydroxide (\( Ca(OH)_2 \)).

The balanced chemical equation for the double displacement reaction of sodium carbonate (\( Na_2CO_3 \)) and calcium hydroxide (\( Ca(OH)_2 \)) is:

\[
Na_2CO_3 + Ca(OH)_2 \rightarrow 2NaOH + CaCO_3
\]
10. This Exploration includes one example each for the five types of reactions. List one other example for each of the five types of reactions.

**Answer:**

a. Single Displacement Reaction: \( \text{Cu} + 2\text{AgNO}_3 \rightarrow \text{Cu(NO}_3)_2 + 2\text{Ag} \)

b. Double Displacement Reaction: \( \text{NaCl} + \text{KNO}_3 \rightarrow \text{KCl} + \text{NaNO}_3 \)

c. Synthesis Reaction: \( 8\text{Fe} + \text{S}_8 \rightarrow 8\text{FeS} \)

d. Decomposition Reaction: \( 2\text{H}_2\text{O} \rightarrow 2\text{H}_2 + \text{O}_2 \)

e. Combustion Reaction: \( \text{C}_{10}\text{H}_8 + 12\text{O}_2 \rightarrow 10\text{CO}_2 + 4\text{H}_2\text{O} \)
Overview

The rate at which a chemical reaction proceeds depends on various factors. Understanding these factors helps in determining the amount of products form and the rate at which they form. In this Exploration, students vary the initial concentration of the reactants and their temperature and observe their effects on the chemical reaction.

Student Learning Objectives

- Examine the molecular view of chemical reactions to understand the effect of initial concentration and temperature.
- Analyze the graphs of concentration and temperature with time for various chemical reactions.
- Observe the rate of reaction for different chemical reactions.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students understand the factors affecting the rate of chemical reactions. Students select a chemical reaction using the options in the Select Reaction dropdown list. The screen displays 0.75 moles of each reactant of the selected reaction in the Molecular View section. Students can change the concentration of a reactant by selecting it in the Select Reactant dropdown list and then using the Add and Remove buttons. In this Exploration, the minimum concentration of a reactant is 0.75 moles and the maximum is 1.5 moles. Students select the temperature at which the reaction occurs using the options in the Select Temperature dropdown list. They then click on the Start button to examine the collision of reactants and the formation of the products, in the Molecular View section. A graph of the concentration of the reactants and the products versus time is plotted in the graph area, under the Molecular View section. Students can use the buttons in the Interactive Key section, to only view the graph they want to analyze.

In the Graph tab, students view graphs of Concentration versus Time or Temperature versus Time for the selected reaction. They select the graph they want to analyze using the options in the Select Graph dropdown list. Students use these graphs to analyze the concentration of reactants and products or the temperature at every point in time, as the reaction proceeds.

In the Tracker tab, students track the initial concentration of the reactants, final concentration of the products, and the time taken for the reaction to complete. They use the buttons in the View
Graph column to examine the Concentration versus Time graph for the reaction. They use the buttons in View Animation column to examine an animation showing the chemical reaction.

**Answers to Questions in the Student Worksheet**

1. Explain endothermic and exothermic reactions.

   **Answer:** A chemical reaction is said to be exothermic when heat is released by the system as the products are formed. A chemical reaction is said to be endothermic when heat is absorbed by the system as the products are formed.

2. Explain the effect of temperature on chemical reactions.

   **Answer:** If the temperature of the reactants is increased, then the molecules gain energy. This increases the number of collisions and the rate at which the reaction occurs.

3. Explain the effect of the initial concentrations of reactants on a chemical reaction.

   **Answer:** If the initial concentrations of the reactants are increased, the rate at which the reaction occurs increases.

4. In this Exploration, select any reaction and observe the time taken for the reaction to complete. Comment on the variation in these values.

   **Answer:** When the reaction H₂ + I₂ → 2HI is selected, the time taken for this reaction to complete for different values of temperature are 5.94 s, 4.75 s, and 3.96 s. It can be observed that as the temperature is increased the time of reaction reduces. This happens because the increase in temperature increases the kinetic energy of the molecules thereby increasing the number of collisions. As the number of collisions increase, the time taken for the formation of products decreases.

5. Explain the term *rate of a chemical reaction*.

   **Answer:** The rate of chemical reaction is the time taken for the reaction to complete. This means that it is the time taken for the reactants to get converted to products.

6. Describe a common example to explain how surface area affects the rate of reaction.

   **Answer:** If sugar is to be dissolved in water, sugar cubes take longer to dissolve completely. However, crushed sugar dissolves readily in water.
7. List the factors affecting the rate of chemical reaction.

   **Answer:** Some of the factors affecting rate of chemical reaction are initial concentration, temperature, nature of the reactants, and surface area of the reactants.

8. Determine if the following statements are true or false. If a statement is false, correct it so that it is true.

   a. Increasing the temperature decreases the rate of chemical reaction.

   b. Increasing the surface area of the reactants does not affect the rate of chemical reaction.

   **Answer:**
   
   a. False. Increasing the temperature increases the rate of chemical reaction.

   b. False. Increasing the surface area of the reactants increases the rate of chemical reaction.

9. Describe a common example explaining how increasing the temperature affects the rate of chemical reaction.

   **Answer:** Water at higher temperature dissolves salt faster as compared to water at a lower temperature.

10. Explain the term catalyst and how it affects the rate of a chemical reaction.

    **Answer:** A catalyst is a substance that is added along with the reactants to increase or decrease the minimum amount of energy required for the products to be formed. It does not participate in the reaction but only affects the rate at which the reaction proceeds.
Hands-On Lab
Classifying and Describing Chemical Reactions

Timing: one 90-minute class session

Objective(s):
Students will carry out five chemical reactions, classify each reaction, write its balanced chemical equation, and describe how the laws of conservation of matter and energy apply.

Safety Precautions:
Remind students to follow all general lab safety rules, wear safety goggles at all times, and not to eat or drink anything in the lab. Students should also be cautioned never leave their Bunsen burner unattended when it is lit, and to use care when handling heated beakers and crucibles. Students should report any difficulties they have with their Bunsen burner immediately to receive help. Remind students that the crucible will remain hot even after the flame is turned off. Students should also report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves. Have students discard their chemical waste in labeled waste containers.

Materials:
Per group:
- 1.0 M Na₂CO₃, 15 mL in a dropper bottle
- 1.0 M HNO₃, 15 mL in a dropper bottle
- 0.5 M Cu(NO₃)₂, 15 mL in a dropper bottle
- 1.0 M KOH, 15 mL in a dropper bottle
- CuSO₄·5H₂O, 1 g
- zinc ribbon, 1 piece
- magnesium ribbon, 1 piece, 0.3 g
- small test tubes, 3
- beaker, 100 mL
- crucible tongs
- crucible with lid
- ring stand and ring with wire gauze
- Bunsen burner
- electronic balance
- goggles, one pair per student
- disposable gloves, one pair per student
- apron, one pair per student
Teacher Preparation:
- Gather materials in advance of students performing the lab.
- Cut zinc ribbon and magnesium ribbon in pieces of about 5 cm length.
- For a class of 30, prepare 250 mL volumes of each solution. Weigh each solute as directed below and transfer into a 250-mL volumetric flask. Add distilled water to the 250-mL mark and then mix thoroughly. For 1.0 M Na₂CO₃, weigh 26.5 g Na₂CO₃.
- For 0.5 M Cu(NO₃)₂, weigh 23.4 g Cu(NO₃)₂.
- For 1.0 M KOH, weigh 14.0 g KOH. (Caution: handle with care; KOH is very corrosive. Be sure to wear safety goggles, gloves, and an apron.)
- For 1.0 M HNO₃, add about 1000 ml water to the volumetric flask first, then transfer 4.9 mL concentrated nitric acid, and dilute to 250 mL. (Caution: handle concentrated acids with care. Always add acid to water, not water to acid. Be sure to wear safety goggles, gloves, and an apron. Work in a hood if possible.)
- Prepare separate waste containers.
- To save time, assign each group one or two reactions and have students share data so that all students have information on all five reactions.

Procedure

Reaction 1:
1. Use the balance to measure the mass of the empty crucible and lid to the nearest 0.1 g. Record the mass.
2. Use the balance to measure the mass of the crucible, lid, and magnesium to the nearest 0.1 g. Record the mass.
3. Adjust the ring stand and ring so that the ring is about 10 cm above the top of the Bunsen burner. Place the wire gauze on top of the ring. Place the crucible with the magnesium ribbon on top of the wire gauze. Place the lid at an angle on the crucible so that there is a small space left open.
4. Light the Bunsen burner and adjust it to give a hot blue flame. Place the burner under the crucible and heat until you see smoke or light coming from inside the crucible. Very carefully use the tongs to adjust the lid so that it completely covers the crucible.
5. Heat for another 2 minutes. Then, use the tongs to lift the lid slightly to let in more air. Quickly replace the lid. Repeat 4 more times.
6. Turn off the burner and allow the crucible and its contents to cool for 15 minutes. Go on to another reaction while you wait.
7. Once the crucible is cool, use the tongs to remove the lid. Record your observations of any changes in the magnesium. Record your observations.
8. Have your teacher check to be sure the crucible is cool enough to touch. Weigh the combined crucible, lid, and reaction product on the balance. Record your data.

Reaction 2:
1. Observe the 1.0 M Na₂CO₃ and 1.0 M HNO₃ solutions. Record your observations.
2. Add 10 drops of 1.0 M Na₂CO₃ to a test tube.
3. Add 10 drops of 1.0 M HNO₃ solution to the same test tube. Swirl to mix. Feel the bottom of test tube. Record your observations.
Reaction 3:
1. **Clean the surface of the zinc ribbon with fine steel wool. Be careful to avoid fingerprints on reacting surface.**
   1. Observe the zinc ribbon and the 0.5 M Cu(NO₃)₂ solution. Record your observations.
   2. Measure the mass of the zinc ribbon.
   3. Add 10 drops of 0.5 M Cu(NO₃)₂ solution to a test tube.
   4. Place an empty 100-mL beaker on the balance. Place the test tube containing the solution in the beaker. Measure the mass of the beaker and the test tube.
   5. Add the zinc ribbon to the same test tube and record your observations. Feel the bottom of test tube. Observe the test tube for 5 minutes. Record your observations.
   6. Place the test tube in the beaker, and measure the mass of the beaker, the test tube, and its contents. Record your data.

Reaction 4:
1. Observe the 1.0 M KOH and 1.0 M HNO₃ solutions. Record your observations.
2. Add 10 drops of 1.0 M KOH to a test tube.
3. Add 10 drops of 1.0 M HNO₃ to the same test tube. Feel the bottom of test tube. Record your observations.

Reaction 5:
1. Use the balance to measure the mass of an empty 100-mL beaker to the nearest 0.1 g. Record your data.
2. Add about 1 g copper sulfate pentahydrate, CuSO₄·5H₂O, to the beaker. Measure the mass to the nearest 0.1 g. Record your data – both mass and appearance of the reactant.
3. Adjust the ring stand and ring so that the ring is about 10 cm above the top of the Bunsen burner as you did for the first reaction. Place the wire gauze on the ring and then place the beaker containing the copper sulfate pentahydrate on the wire gauze.
4. Light the Bunsen burner and adjust it to give a hot blue flame. Place the burner under the beaker and heat for 8 to 10 minutes. Record your observations as the reaction progresses.
5. Turn off the burner and allow the beaker and its contents to cool for 10 minutes.
6. Have your teacher check to be sure the beaker is cool enough to touch. Use the balance to measure the combined beaker and its contents. Record your data, both mass and appearance of the product.

**Analysis and Conclusions**

1. Write a balanced chemical equation for each chemical reaction. Remember that some reactants and products may be gases.

   *Reaction 1:* \(2 \text{Mg(s)} + \text{O}_2(g) \rightarrow 2\text{MgO(s)}\)

   *Reaction 2:* \(\text{Na}_2\text{CO}_3 \text{(aq)} + 2\text{HNO}_3 \text{(aq)} \rightarrow 2\text{NaNO}_3 \text{(aq)} + \text{CO}_2(g) + \text{H}_2\text{O(l)}\)

   *Reaction 3:* \(\text{Zn(s)} + \text{Cu(NO}_3)_2\text{(aq)} \rightarrow \text{Cu(s)} + \text{Zn(NO}_3)_2\text{(aq)}\)

   *Reaction 4:* \(\text{KOH(aq)} + \text{HNO}_3 \text{(aq)} \rightarrow \text{KNO}_3 \text{(aq)} + \text{H}_2\text{O(l)}\)
Reaction 5: \( \text{CuSO}_4 \cdot 5\text{H}_2\text{O}(s) \rightarrow \text{CuSO}_4(s) + 5\text{H}_2\text{O}(g) \)

2. Classify each reaction according to its type and explain the evidence you used to make the classification.

Reaction 1 can be classified as a combustion reaction and also as a synthesis reaction. The magnesium changed color and appeared to have a coating of gray fuzz. The reaction needed air to occur, indicating that oxygen is a likely reactant. Also, the mass of the solid product was greater than the mass of the magnesium. Because reactions do not create mass, the mass is likely to have come from a gaseous reactant.

Reaction 2: \( \text{Na}_2\text{CO}_3(\text{aq}) + \text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{CO}_2(\text{g}) \)
This can be classified as a double-displacement reaction. Bubble evolution provided evidence that one of the products was a gas, constituent with \( \text{CO}_2 \) formation.

Reaction 3: \( \text{Zn}(s) + \text{Cu(NO}_3)_2(\text{aq}) \rightarrow \text{Cu}(s) + \text{Zn(NO}_3)_2(\text{aq}) \)
This can be classified as a single-displacement reaction. The zinc dissolved and a reddish-orange precipitate that could be copper metal formed. The blue color of the copper ion (\( \text{Cu}^{2+} \)) solution gradually lightened as the ion was converted to copper metal.

Reaction 4: \( \text{KOH}(\text{aq}) + \text{HNO}_3(\text{aq}) \rightarrow \text{KNO}_3(\text{aq}) + \text{H}_2\text{O}(l) \)
This can be classified as a double-displacement reaction. The reaction solution got very warm, indicating that a chemical change was taking place, even though there were no visible signs of a chemical reaction.

Reaction 5: \( \text{CuSO}_4 \cdot 5\text{H}_2\text{O}(s) \rightarrow \text{CuSO}_4(s) + 5\text{H}_2\text{O}(g) \)
This can be classified as a decomposition or dehydration reaction. The blue solid turned white as water vapor exited the beaker. The mass of the solid product was lower than the mass of the solid reactant, which could be explained by a gaseous product.

3. Describe how the law of conservation of matter applies to these reactions. Explain whether your mass measurements support or contradict this law.

Matter is not created nor destroyed in any chemical reactions, include these five reactions. Balanced chemical equations for each reaction show that matter is conserved. For Reaction 1, the measured mass of the reactant was less than the product. For Reaction 3, the total mass of the reactants was the same as the total mass of the products. For Reaction 5, the measured mass of the reactant was greater than the product. Reaction 3 shows that mass is conserved. However, Reactions 1 and 5 were not done in closed systems and gas could enter and leave during the reactions. Only the mass of the solid reactant and/or product was measured, so these measurements do not contradict the law.

4. Classify each reaction as endothermic or exothermic. Provide evidence for your explanation.

Reaction 1 was exothermic. Although heat was needed to start the reaction, it released light.

Reaction 2 was exothermic because the test tube felt warm during the reaction.

Reaction 3 was exothermic because the test tube felt warm during the reaction.

Reaction 4 was exothermic because the test tube felt warm during the reaction.
Reaction 5 was most likely endothermic because it required heat to occur and did not seem to release heat or light.

5. Describe how the law of conservation of energy applies to these reactions. How can exothermic and endothermic reactions be explained using the law of conservation of energy?

Energy is not created nor destroyed in any these chemical reactions. For the exothermic reactions, the heat that was felt was stored in the chemical bonds of the reactants. Heat was released because less energy was stored in the bonds of the reactants than in products. For the endothermic reaction, the energy take in by the reaction is now stored in the chemical bonds of the products. Although energy may have changed forms between chemical, light, and thermal energies, the total amount of energy did not change.

In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and/or the SI (metric) system to accurately measure:
    - Mass
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Touching (temperature, texture, shape, size, vibration, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identifies and interprets:
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Using data to determine the cause effect relationship observed in the investigation

- **Communication in Science**
  - Report results using:
    - Table/graph showing data

- **Scientific Investigation**
  - Scientific Investigation:
    - Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
    - Scientific claims are based on data and reliable scientific sources.
English Language Proficiency Activity

Concept: Chemical Reactions and Equations

Overview: You will create your own glossary using words and pictures to help make sense of written text. You will enhance and confirm your understanding of the text by creating your own definitions for important vocabulary words and sharing your work with a partner.

Directions:

1. With help from your teacher, use the video and animations in the Interactive Glossary to create a list of important vocabulary terms in the Explore activities of “Chemical Reactions and Equations.”
2. For each vocabulary word, add words that help, a picture or example, and a definition in your own words.
3. Compare your chart with a partner. Discuss the pictures and definitions that you chose for each word. Does your partner agree with your pictures and definitions? Why or why not?
4. Work with your partner to make any changes to your chart that might be needed.

What parts of Techbook are you using? ________________________________

Who are you working with?
the whole class a group one other person nobody

What will you have when you finish? ________________________________

Words to Know:

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<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
<th>My definition</th>
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### English Language Proficiency Activity

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<th>Picture or example</th>
<th>My definition</th>
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### Discussion Questions:

- Does your partner agree with your pictures or examples and your definitions? Why or why not?

- Are there any changes that you should make to your chart?
Hands-On Lab
Name That Chemical Reaction

Timing: one 90-minute class session

Objective(s):
Students will work at stations to conduct demonstrations of different types of chemical reactions and will write a balanced chemical equation for each reaction.

Safety Precautions:
- Do not use very strong acids or bases for this lab.
- Remind students to follow all general lab safety rules, wear closed-toe shoes, and not to eat or drink anything in the lab.
- Students should never leave the lab area unattended with chemicals sitting out.
- Remind students to wear safety equipment including goggles, gloves, and lab aprons.
- Students should follow all instructions for disposal and cleaning of the chemicals and their containers. This rule includes the use of and disposal of resources including chemicals in a safe manner according to the teacher’s instructions.
- Also remind students to be careful not to contaminate reagent stocks by returning unused or leftover chemicals to the reagent containers.
- Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

Materials:
For the Teacher Demonstration:
- 40 mL ethanol
- 250 mL beaker
- 5 gallon water jug (clean and dry)
- stopper for the water jug
- matches
- meter stick
- tape
Per Class:
- copper wire (approximately 5 cm long each), 5 pieces
- pair of tongs, 2
- Bunsen burner
- 3% hydrogen peroxide solution, 125 mL
- 250 mL beakers, 5
- active dry yeast, 1–2 packets
- small spoon or scooper (approximately 0.5 mL)
- copper (II) sulfate solution in a labeled test tube, 20 mL
- 100 mL beaker
- iron wire, 5 pieces
- sandpaper or steel wool, 2 pieces
- test tube racks, 2
- 0.5 M calcium chloride, 5 mL
- 0.5 M sodium carbonate, 5 mL
- unlabeled test tubes, 5
- 150 mL tap water
- plastic 1 mL pipettes, 4
- stir plate
- magnetic stir bar
- bromothymol blue, 10 mL
- 0.1 M hydrochloric acid solution (HCl), 10 mL
- 0.1 M sodium hydroxide solution (NaOH), 10 mL
- stopwatch or timer, 3
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student

Teacher Preparation:
- Use caution when igniting ethanol in the combustion demonstration. Make sure the table surface has been cleared and it has been wiped down to remove any residual substances that may be flammable.
- Pick five appropriate areas in the classroom, one for each station. Post a number for each area, 2 through 6. Note that Station 1 is a teacher-directed demonstration. Do not post the type of chemical reaction represented at each station. Students will determine this as they observe reactions and complete chemical equations.
- Print the list of materials and directions and post them at each station (see Directed Inquiry section below.) Note that each list of materials in this section is
for one group to rotate through the station. Appropriate quantities for the entire class are listed in the Materials section of the lab.

- Place appropriate supplies at each station. Designate an area for clean and dirty glassware at appropriate stations.
- Prepare five note cards with the following information and post them at the appropriate stations. (Note: these equations are not balanced/complete—students will balance or complete them in their notes as they work at each station.)

  One side: Station 2 Chemical Equation
  Other side: Fe(?) + CuSO₄(?) → FeSO₄ (?) + Cu(?)
  This equation is balanced. Write out the equation in your notes and fill in “s” for solid or “aq” for aqueous (water solution) in each set of parenthesis.

  One side: Station 3 Chemical Equation
  Other side: H₂O₂ → H₂O + O₂(g)
  This equation is NOT balanced. Write it out and balance it in your notes.

  One side: Station 4 Chemical Equation
  Other side: HCl + NaOH → ??? + HOH
  This equation is balanced. Think about what you have learned about acid base reactions and look at the given reactants and the given product of this equation. Try to figure out what compound (the missing product) should be filled in where the question marks are. Write the completed equation in your notes.

  One side: Station 5 Chemical Equation
  Other side: Cu + O₂ → CuO
  This equation is NOT balanced. Write it out and balance it in your notes.

  One side: Station 6 Chemical Equation
  Other side: CaCl₂(aq) + Na₂CO₃(aq) → CaCO₃(s) + NaCl(aq)
  This equation is NOT balanced. Write it out and balance it in your notes.

- Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed
Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry

Combustion Demonstration (Station 1)

Start with this demonstration before students rotate through the remaining stations with their lab groups.

1. Post materials for this reaction somewhere in the room for students to see:
   - 40 mL ethanol \( (C_2H_5OH) \)
   - 250 mL beaker
   - 5-gallon water jug (clean and dry)
   - stopper for the water jug
   - matches
   - meter stick
   - tape

2. Using the beaker, measure 40 mL of ethanol and pour it into the 5-gallon jug.
3. Put the stopper on the jug and carefully roll it on its side so the entire inner surface of the jug comes into contact with the ethanol.
4. Pour excess liquid back into the beaker, and set the beaker and the stopper at least two meters away from the demonstration area. Clean up any ethanol spills on the demonstration area.
5. Tell students to look at the materials for this reaction and to think about the different types of chemical reactions they have learned about.
6. Ask students to predict, in their notes, what kind of reaction will occur.
7. Dim the lights in the room. Make sure students are sitting at least four meters away from the demonstration area.
8. Tape a match to the end of a meter stick. Light the match away from the jug. Standing away from the jug, hold the match over the opening to ignite the ethanol.

9. Have students record their observations in their notes.

10. Write the unbalanced chemical equation on the board: \( \text{C}_2\text{H}_5\text{OH}(l) + \text{O}_2(g) \xrightarrow{\text{Heat}} \text{CO}_2(g) + \text{H}_2\text{O}(g) \)

11. Demonstrate how to balance this equation. Students should be writing the steps for balancing the equation in their notes as you work through it. \( \text{C}_2\text{H}_5\text{OH}(l) + 3 \text{O}_2(g) \xrightarrow{\text{Heat}} 2 \text{CO}_2(g) + 3 \text{H}_2\text{O}(g) \)

12. Ask students to share their predictions about which type of chemical reaction was shown in this demonstration (combustion.) Have them adjust their predictions as needed. Were they correct? Why or why not?

Divide the class into five small lab groups. Tell students that they will have approximately 10–15 minutes at each station to observe a chemical reaction and to correctly complete the chemical equation for each reaction. Model the steps for each demonstration before students rotate through them and remind students to record their observations and results in their notes.

**Station 2:**

**Materials:**
- 20 mL copper (II) sulfate solution in a test tube (CuSO₄)
- piece of iron wire (Fe)
- piece of sandpaper or steel wool
- test tube rack
- tongs
- stopwatch or timer

**Directions:**
1. Do not flip over the card labeled “Station 1 Chemical Equation”!
2. Review the directions, and look at the materials needed for this station.
3. Write a hypothesis about what type of chemical reaction will occur.
4. Take a piece of iron wire, and sand it with a piece of sandpaper or steel wool to remove any rust.
5. Record observations of the iron wire.
6. Practice holding the piece of iron wire at one end with the tongs.
7. Dip the iron wire into the test tube labeled “copper (II) sulfate solution” for 20 seconds.
8. Record observations regarding changes to the iron wire and the solution.
9. Flip over the chemical equation card, and work with your partners to correctly complete it in your notes.
10. Use the chemical equation to determine the type of chemical reaction that occurred. Was your hypothesis correct? Record answers in your notes.
11. In your notes, identify the source for each element or compound in the chemical equation. (example: Cu = wire)
12. Discard the iron wire, and turn the equation card face down before leaving the station.

Station 3:
Materials:
- 3% hydrogen peroxide solution (H₂O₂), 125 mL
- 250 mL beaker (clean and dry)
- active dry yeast
- small spoon or scoop (approximately 5 mL)
- stopwatch or timer

Directions:
1. Do not flip over the card labeled “Station 2 Chemical Equation”!
2. Review the directions, and look at the materials needed for this station.
3. Write a hypothesis about what type of chemical reaction will occur.
4. Pour 25 mL of hydrogen peroxide into a clean and dry 250 mL beaker.
5. Add 0.5 mL of dry active yeast to the hydrogen peroxide.
6. Observe the reaction for one minute.
7. Record observations regarding any changes that take place in the beaker.
8. Flip over the chemical equation card, and work with your partners to correctly balance it in your notes.
9. Use the chemical equation to determine the type of chemical reaction that occurred. Was your hypothesis correct? Record answers in your notes.
10. In your notes, identify the source for each element or compound in the chemical equation. (example: Cu = wire)
11. Pour the contents of the beaker down the drain with water and turn the equation card face down before leaving the station.
Station 4:
Materials:
- 150 mL tap water
- plastic 1 mL pipets, 2
- stir plate
- magnetic stir bar
- bromothymol blue solution
- 0.1 M hydrochloric acid solution (HCl)
- 0.1 M sodium hydroxide solution (NaOH)

Directions:
1. Do not flip over the card labeled “Station 3 Chemical Equation”!
2. Review the directions, and look at the materials needed for this station.
3. Write a hypothesis about what type of chemical reaction will occur.
4. Add 150mL of tap water to a 250 mL beaker.
5. Set beaker on the stir plate, and place a magnetic stir bar inside the beaker.
6. Add 10 drops of the bromothymol blue to the beaker.
7. Record observations.
8. Add drops of the 0.1 M hydrochloric acid solution to the water until you notice a color change.
9. Record observations.
10. Add drops of 0.1 M sodium hydroxide solution to the water until the color changes again.
11. Record observations.
12. Flip over the chemical equation card, and work with your partners to correctly complete it in your notes.
13. Use the chemical equation to determine the type of chemical reaction that occurred. Was your hypothesis correct? Record answers in your notes.
14. In your notes, identify the source for each element or compound in the chemical equation. (example: Cu = wire)
15. Discard the contents of the beaker down the drain with water, turn off the stir plate, and turn equation card face down before leaving this station. Thoroughly rinse the beaker. Make sure the magnetic stir bar does not go down the drain!
Station 5:
Materials:
- 5 cm piece of copper wire (Cu)
- pair of tongs
- Bunsen burner
- piece of sandpaper or steel wool
- stopwatch or timer

Directions:
1. Do not flip over the card labeled “Station 4 Chemical Equation”!
2. Review the directions, and look at the materials needed for this station.
3. Write a hypothesis about what type of chemical reaction will occur.
4. Take a piece of copper wire, and practice holding it with a pair of tongs.
5. Clean the copper wire with the sandpaper or steel wool.
6. Record observations of the copper wire.
7. Carefully ignite the Bunsen burner.
8. Hold the copper wire with the tongs into the hottest part of the flame for two minutes.
9. Turn off the Bunsen burner.
10. Record observations about any changes to the copper wire in your notes.
11. Flip over the chemical equation card, and work with your partners to correctly balance it in your notes.
12. Use the chemical equation to determine the type of chemical reaction that occurred. Was your hypothesis correct? Record answers in your notes.
13. In your notes, identify the source for each element or compound in the chemical equation. (example: Cu = wire)
14. After the copper wire has cooled, discard it and turn equation card face down before leaving the station.

Station 6:
Materials:
- test tube rack
- 0.5 M calcium chloride (CaCl₂), 5 mL
- 0.5 M sodium carbonate (Na₂CO₃), 5 mL
- clean and dry test tube
- 1 mL pipettes, 2
Directions:
1. Do not flip over the card labeled “Station 5 Chemical Equation”!
2. Review the directions, and look at the materials needed for this station.
3. Write hypothesis about what type of reaction will occur.
4. Measure 1 mL of 0.5 M calcium chloride in a pipette, and add it to a clean and dry test tube.
5. Record observations of the calcium chloride.
6. Measure 1 mL of 0.5 M sodium carbonate in a pipette, and then add it to the calcium chloride in the test tube.
7. Record your observations about any changes that took place in the test tube after adding the sodium carbonate.
8. Flip over the chemical equation card, and work with your partners to correctly balance it in your notes.
9. Use the chemical equation to determine the type of chemical reaction that occurred. Was your hypothesis correct? Record answers in your notes.
10. In your notes, identify the source for each element or compound in the chemical equation. (example: Cu = wire)
11. Dispose of the contents of the test tube down the drain with plenty of water, and turn the equation card face down before leaving this station.

Wrap Up
1. Have students return to their seats.
2. Review the types of chemical reactions that occurred at each station and the correct chemical equation for each:
   • Station 2- Single Replacement- \( \text{Fe} (s) + \text{CuSO}_4 (aq) \rightarrow \text{FeSO}_4 (aq) + \text{Cu} (s) \)
   • Station 3- Decomposition- \( 2\text{H}_2\text{O}_2 \rightarrow 2\text{H}_2\text{O} + \text{O}_2(g) \)
   • Station 4- Acid Base- \( \text{HCl} + \text{NaOH} \rightarrow \text{NaCl} + \text{HOH} \)
   • Station 5- Synthesis- \( 2\text{Cu} + \text{O}_2 \rightarrow 2\text{CuO} \)
   • Station 6- Double Replacement- \( \text{CaCl}_2(aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow \text{CaCO}_3(s) + 2\text{NaCl}(aq) \)
Guided Inquiry

Students can develop their own procedures for demonstrating chemical reactions and recording observations based on their knowledge of the content and materials provided.

1. Divide students into five groups.
2. Give each group one of the chemical equations from the Directed Inquiry activity, excluding the combustion equation.
3. Tell students that each group will be responsible for reporting to the class the type of chemical reaction that is represented by their assigned equation. Each group will also be responsible for researching a safe procedure for carrying out this reaction. Provide the groups with a list of available materials for their assigned equation.
4. Groups will present their findings to the class. Once the teacher approves the procedure, all students will use this procedure to carry out the chemical reaction. Students should record the approved procedure in their notes prior to conducting the reaction. Students can rotate through stations or complete all reactions in small groups at lab tables.
5. The combustion reaction should be completed as a teacher demonstration first.

Ask the students some guiding questions to help them focus their inquiry:

• What resources can you use to figure out what type of reaction the chemical equation represents?
• What are some general rules about safety when working with chemicals?

Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions or assigning them as homework:

1. When you held the copper wire in the flame, did a physical change or a chemical change occur, and how could you tell? The flame itself changed color and the copper wire was dark where it had touched the flame.

2. In the reactions of the iron wire and the copper sulfate solution, how did you know that a chemical reaction had taken place? Were there changes in both reactants or only in one? How could you tell? Given the information in the chemical equation, what kind of reaction was this? Both reactants changed. The iron wire became narrower (loss mass) and the solution changed color. According to the chemical equation, this was a single displacement reaction.
3. In the acid base reaction, is bromothymol blue a part of the chemical equation? Given what you observed as the chemical reaction took place, hypothesize the role of bromothymol blue in this demonstration. As the acids and bases were added to the beaker the bromothymol blue allowed us to see that the pH was changing. (Some students may know that it is a pH indicator.) It was not a part of the chemical equation because it did not react with the HCl or NaOH.

4. Hydrogen peroxide naturally decomposes into water and oxygen very slowly. All aerobic organisms (organisms that use oxygen) produce hydrogen peroxide as part of metabolism. Hydrogen peroxide can damage living cells, thus all aerobic organisms have enzymes that catalyze—speed up—it decomposition. What is yeast, and what was the likely role of the yeast in the decomposition reaction? Some students may know that yeast is a fungus. Most should be aware that yeast is a living thing. In this experiment, the yeast supplied the enzyme that helped rapidly decompose the hydrogen peroxide.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Make or use models that:
    - Function exactly like or similarly to the real thing
    - Apply mathematical operations and principles to replicate the real thing.
    - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Time
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Bunsen burner
    - Clock/stopwatch
    - Pipette
    - Graduated cylinder
    - Test tube
    - Other Laboratory equipment
  - Use senses to observe:
• Seeing (color, shape, size, texture, motion)
• Hearing (pitch, volume, reflection, direction)
  - Use the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

• Interpret Data
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic

• Evaluate Evidence
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis

• Communication in Science
  - Report results using:
    - Peer presentation
    - Scientific explanations/arguments

• Patterns and Systems
  - Patterns and Change:
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    - Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    - Many patterns in nature occur in cycles.
    - Mathematical patterns help to predict future events and describe change in systems.
  - Systems:
    - Physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.
    - No matter how substances within a closed system interact with one another, or how they combine or break apart, the total mass of the system remains the same.
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.

• Scientific Investigation
  - Scientific Investigation:
- Science investigation begins with a testable question.
- Scientific investigation results in things we know and things we don't know.
- Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
    - It is important in science to keep honest, clear, and accurate records.
- Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientific claims can be substantiated using data and observation.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’ c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term 'toggle.'

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

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Name _____________________________  
Date _____________________________

English Language Proficiency Activity

Concept: Mathematics of Formulas and Equations

Overview: You will listen to and watch a video segment and then write a question that you have about what you heard and saw.

Directions:

1. Listen to and watch the video segment "Limiting Reagent."
2. Write one question that you have about what you heard or saw in the video.
3. Your teacher will post all of the questions that the class has asked.
4. Work with a partner to try to answer as many of the questions that are posted.
5. Your teacher will lead a class discussion on each of the questions and help to clarify any issues.

What parts of Techbook are you using? ____________________________________

Who are you working with?
the whole class  a group  one other person  nobody

What will you have when you finish? ______________________________________

Words to Know: Add key words and a picture or example to help you remember each word.

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>limiting</td>
<td></td>
<td></td>
</tr>
<tr>
<td>reagent</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Write one question that you can answer about the video segment.

_____________________________________________________

Write one question that you cannot answer about the video segment.

_____________________________________________________

_____________________________________________________
Hands-On Activity
Limiting Reagent

Objective:
Students will use a model to conduct a chemical reaction and determine the limiting reagent.

Estimated time to complete: 10 minutes

Materials:
For each pair of students:
  - Plastic bag labeled #1: bolts (7), nuts (10), washers (12)
  - Plastic bag labeled #2: bolts (12), nuts (8), washers (6)

Procedure:
Organize students in pairs. Provide each pair with the two bags containing bolts, nuts, and washers. None of these items should be assembled.

Instruct students to consider the items to be newly discovered reactants that will take part in a chemical reaction. Have students work with their partner to decide on element symbols to represent their reactants. Creativity is encouraged.

Next ask students to use their reactants in bag #1 to carry out the chemical reaction by building a nut-washer-bolt compound. Have them write the balanced chemical equation to describe this reaction. Ask students to determine the limiting reagent in this case. (N + B + W → NBW; The bolts were limiting.)

Then, have students repeat the activity using bag #2. Ask students how this reaction differed from the first. (The same reaction occurred, but this time the washers were limiting.)

Ask students which plastic bag gave the greatest product yield. (Bag #1 yielded 7 products, while bag #2 only yielded 6 products.)

Ask students to think about the following questions as they carry out this activity:
  - What does a balanced chemical reaction tell you?
  - Why might the limiting reagent be one reactant in one case and a different reactant another time you run the reaction?
  - What effect does the limiting reagent have on the outcome of a reaction?
  - Why were you unable to have 100% yield of nut-washer-bolt compound in this activity?
  - How could you change the activity so that you are able to have 100% yield?
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Apply mathematical operations and principles to replicate the real thing

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)

- **Interpret Data**
  - Identify and interpret patterns using:
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation

- **Patterns and Systems**
  - Patterns and Change:
    - Mathematical patterns help to predict future events and describe change in systems.

- **Scientific Investigation**
  - Scientific Investigation:
    - Scientific investigations lead to the development of scientific explanations.

- **Scientific Endeavor**
  - Characteristics of Science:
    - One way to make sense of something is to think of how it relates to something more familiar
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Exploration Teacher Guide: Mathematics of Formulas and Equations

Overview

Students are introduced to stoichiometric principles such as yield of a reaction and limiting reactant. They use data provided in the Exploration to calculate the values of formula mass and percent yield.

Student Learning Objectives

- Observe the products of selected chemical reactions.
- Calculate the formula mass of reactants and products.
- Calculate the percent yield of a chemical reaction.
- Identify the limiting reactant in a chemical reaction.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students calculate the value of stoichiometric parameters to determine the percent yield of a chemical reaction. They begin by selecting reactants from the Select Reactants dropdown list. The initial weight of one of the reactants and final weight of the product is displayed. Students calculate the formula mass of the reactants and products and select the correct answer using the radio buttons. The answer is validated using the Submit button.

Students then click the Proceed button to calculate the number of moles of the reactants and products, select the correct answer and validate their answers using the Submit button. Next, they calculate the percent yield of the reaction, and initial weight of the reactant. Finally, they identify the limiting reactant in the chemical reaction.

Students can use the Hint button at any point in the Exploration to view the formulas used for calculating the value of stoichiometric parameters. They can use the Show Me! button to generate the correct answers if they are unable to do so. The Reset button restarts the Exploration.

Students can use the Tracker tab to review the stoichiometric values of the correctly completed reactions.
Answers to Questions in the Student Worksheet

1. Describe the formula for calculating the yield of a chemical reaction as a percentage.

   **Answer:** The formula for calculating the percent yield of a chemical reaction is given by:
   \[
   \text{Percent yield} = \left( \frac{\text{Actual Mass of the Product}}{\text{Predicted Mass of the Product}} \right) \times 100
   \]
   The actual mass of the product is its observed weight at the end of the chemical reaction. The predicted mass is the product’s formula mass multiplied by its number of moles.

2. Using the Exploration, identify the limiting reactant in the formation of methanol from the reaction of carbon monoxide with hydrogen.

   **Answer:** The limiting reactant in the formation of methanol using carbon monoxide and hydrogen is carbon monoxide.

3. Explain how the atomic weight of reactants is related to their formula mass in a chemical reaction.

   **Answer:** The formula mass of a reactant is the sum of the product of the number of atoms and atomic weights of each of its constituent elements.

4. List three parameters that are required for calculating percent yield of a reaction.

   **Answer:** The actual mass, predicted mass, and number of moles of the product are required for calculating the percent yield of a reaction.

5. Describe the science of stoichiometry.

   **Answer:** Stoichiometry is the set of protocols used to analyze the relation between the ratio of reactants and products in a chemical reaction. Many other chemical parameters are calculated using stoichiometric observations.

6. Explain why the yield of a reaction can never be 100 percent.

   **Answer:** The yield of a reaction can be expected to be 100 percent only theoretically. In reality, this can never be achieved because of the limitations in reaction efficiency and measurement accuracy.
7. Describe how the limiting reactant is identified in a chemical reaction.

Answer: To identify the limiting reactant in a chemical reaction, the number of moles of each of the reactant is compared. Each of the reactants is selected, one by one, and the number of moles of other reactants required to completely use up the reactant chosen is calculated. Now, the moles needed to the actual number of moles present are compared. The reactant which has fewer actual number of moles than the number of moles needed is the limiting reactant.

8. Distinguish between molecular formula and empirical formula of a compound.

Answer: The molecular formula of a compound gives the number of each type of atoms in a compound. The empirical formula, on the other hand is the simplest positive integer ratio of atoms of each element found in a compound.

9. Explain the role of catalysts in chemical reactions.

Answer: A catalyst is a substance that affects the rate of a chemical reaction, without itself taking part in the reaction. At the end of the reaction, the catalyst can be easily isolated from the products. Catalysts are widely used in industry to increase the throughput of various reactions.

10. Define stoichiometric ratio.

Answer: Stoichiometric ratio is defined as the coefficient of one reactant divided by the coefficient of another reactant. This coefficient can relate to any one of the parameters used in stoichiometric calculations.
Hands-On Lab
Stoichiometry of a Reaction

Timing: one 90-minute class session

Objective(s):
In this activity, students will carry out an oxidation-reduction reaction between iron and copper sulfate and use the results to determine the reaction stoichiometry. As part of the activity, students will develop hypotheses, design their own procedure, and learn analytical laboratory skills.

Safety Precautions:
Students should be cautioned that acetone is a volatile, flammable liquid. No Bunsen burners or other open flame source should be used during this lab. All waste should be discarded in properly labeled waste containers and not down the drain. Students should wear safety goggles, lab aprons, and closed-toe shoes during the lab.

Materials:
For teacher demonstration:
- acetone (20 mL)
- beaker, 50 mL
- aluminum metal
- electronic balance (±0.001 g)
- Erlenmeyer flask, 125 mL
- filter paper, 9.0 cm
- graduated cylinder, 25 mL
- gravity funnel
- paper towel
- wash bottle
- water, deionized or distilled
- 0.5 M zinc nitrate solution, Zn(NO₃)₂ (20 mL, prepared as described below)

Per student:
- acetone (20 mL)
- beaker, 50 mL
- 0.5 M copper sulfate solution, CuSO₄ (20 mL, prepared as described below)
- Erlenmeyer flask, 125 mL
- filter paper, 9.0 cm
- graduated cylinder, 25 mL
- gravity funnel
- iron wool
- paper towel
• stirring rod
• wash bottle
• water, deionized or distilled

Per class (Guided Inquiry):
• electronic balance (±0.001 g), at least 2

Teacher Preparation:
• Prepare 20 mL 0.5 M zinc nitrate (Zn(NO₃)₂) solution for each class demonstration. Measure 1.89 g Zn(NO₃)₂ (or 2.97 g Zn(NO₃)₂ • 6H₂O) and mix with deionized or distilled water to give a final volume of 20 mL.
• Cut one piece of aluminum metal to about 1 cm × 2 cm size.
• Prepare 500 mL 0.5 M CuSO₄ solution for each class of 20 students. Measure 64.422 g CuSO₄ • 5H₂O (copper sulfate pentahydrate) and mix with deionized or distilled water to give a final volume of 500 mL.
• Prepare a properly labeled waste container to collect liquid waste.
• Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
1. Review the concept of reaction stoichiometry using the following example. Start by writing the following equation on the board:

\[
2\text{Al}(s) + 3\text{Zn(NO}_3\text{)}_2(aq) \rightarrow 3\text{Zn}(s) + 2\text{Al(NO}_3\text{)}_3(aq)
\]
Ask students to identify the stoichiometric relationship between aluminum (Al) and zinc (Zn). (The stoichiometric relationship is the mole ratio, or 2Al:3Zn.)

2. Show a beaker containing 20 mL 0.5 M Zn(NO₃)₂ solution. Ask students to make observations of the solution. (The solution is clear and colorless.) Show a piece of aluminum and ask for observations. (The metal is shiny, silver, and solid.) Drop the aluminum metal into the Zn(NO₃)₂ solution. Ask students to make observations. (The aluminum metal dissolves and a dark solid forms on the bottom of the beaker.) Ask students what this dark solid is. (zinc metal) Ask students what else is present (Al⁺³ ions and NO₃⁻ ions, but these are not visible). Ask students which product will be easiest to measure at the end of the reaction and why. (The zinc will be easiest to measure because it is a solid and can be seen.) If a student does not suggest it, tell the class that the zinc product can be more easily isolated than anything else in the reaction mixture because it is a solid. Filtration is a simple yet effective means for separating a solid from a solution.

3. Demonstrate how to filter the zinc solid from the reaction solution. First weigh a piece of filter paper and record the mass to the nearest 0.001 g. Fold the filter paper in half and then in half again. Open the paper so that it forms a cone and place it in the gravity funnel. Place the gravity funnel in the Erlenmeyer flask. Use a small amount of deionized (or distilled) water from a wash bottle to wet the filter paper. This will allow it to stick to the funnel. Then pour the reaction mixture into the filtration setup. Rinse the beaker with water from the wash bottle and pour that into the filtration apparatus as well. Ask students why you did this wash step. (to transfer all of the zinc product) Allow the solution to drain through the paper and then rinse the paper with 20 mL acetone. Explain that acetone will displace any water present on or in the paper. Because acetone is so volatile, it will dry more rapidly than water. (Note: The video segment The Acetic Acid/Sodium Acetate Buffer System (5:26–5:36; omit audio) can also be used to illustrate the gravity filtration procedure.)

4. Carefully remove the filter paper containing the zinc product from the funnel. Lay it open on a paper towel. Allow students to observe that it is damp. Tell students that you want to weigh the zinc to determine how much was produced. Ask whether you should weigh it now (no, because the filter paper is damp and the liquid will add mass to the reading). Ask students how they will know when the filter paper is dry (when it looks dry and when it feels dry to the touch). Instruct students to take several mass readings over a period of time. Ask what will be observed (mass readings will decrease as the paper dries). Ask students when they can stop taking mass readings (when the mass no longer changes).

5. Ask students how they can determine the stoichiometry of reaction between Al and Zn. (convert masses of Al and Zn to moles and compare the two mole values)
6. Introduce the reaction that students will be running:

\[
\text{Fe(s) + CuSO}_4\text{(aq) } \rightarrow \text{?}
\]

Tell students that iron can be oxidized to the +2 state or the +3 state. Ask what iron product will form in the reaction above if iron is oxidized to the +2 state. (iron(II) sulfate, FeSO}_4; ferrous sulfate) Ask what iron product will form in the reaction above if iron is oxidized to the +3 state. (iron(III) sulfate, Fe}_2(SO}_4)_3; ferric sulfate)

**Guided Inquiry**

Students can develop their own procedure for investigating the oxidation-reduction reaction between iron and copper. Ask the students some guiding questions to help them focus their inquiry:

- How will this investigation be similar to the one demonstrated?
- How will this investigation be different from the one demonstrated?

1. Introduce the reaction that students will be investigating:

\[
\text{Fe(s) + CuSO}_4\text{(aq) } \rightarrow \text{?}
\]

Remind students that iron can be oxidized to the +2 state or the +3 state. Ask what iron product will form in this reaction if iron is oxidized to the +2 state (iron(II) sulfate, FeSO}_4; ferrous sulfate). Ask what iron product will form in the reaction above if iron is oxidized to the +3 state (iron(III) sulfate, Fe}_2(SO}_4)_3; ferric sulfate).

2. Instruct students to construct two alternative hypotheses. Each hypothesis should include a balanced chemical equation expected for the oxidation-reduction reaction between iron and copper sulfate that produces one of the possible iron products discussed.

(The two alternative hypotheses are:

1) Iron is oxidized to the +2 state, which gives the following balanced equation for the reaction:
\[
\text{Fe(s) + CuSO}_4\text{(aq) } \rightarrow \text{Cu(s) + FeSO}_4\text{(aq)}
\]

2) Iron is oxidized to the +3 state, which gives the following balanced equation for the reaction:
\[
2\text{Fe(s) + 3CuSO}_4\text{(aq) } \rightarrow 3\text{Cu(s) + Fe}_2\text{(SO}_4)_3\text{(aq)}
\]
3. Instruct students to write a step-by-step procedure for their investigation. Tell them to use between 0.2–0.3 g iron and 20.0 mL 0.5 M CuSO₄ solution. Tell them that the acetone wash is limited to 20 mL. Instruct students to obtain your approval of their procedure before they begin.

Sample data:

<table>
<thead>
<tr>
<th>Mass of iron</th>
<th>0.232 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of filter paper</td>
<td>1.005 g</td>
</tr>
<tr>
<td>Repeated weighings of filter paper + copper</td>
<td></td>
</tr>
<tr>
<td>First weighing</td>
<td>1.304 g</td>
</tr>
<tr>
<td>Second weighing</td>
<td>1.275 g</td>
</tr>
<tr>
<td>Third weighing</td>
<td>1.269 g</td>
</tr>
<tr>
<td>Fourth weighing</td>
<td>1.269 g</td>
</tr>
</tbody>
</table>

The data are consistent with a 1:1 stoichiometric ratio between Fe(s) and Cu(s). The balanced chemical equation that fits this ratio is:

\[
\text{Fe(s)} + \text{CuSO}_4(\text{aq}) \rightarrow \text{Cu(s)} + \text{FeSO}_4(\text{aq})
\]

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Did your results support either of your alternative hypotheses? Explain. Yes, my data showed that there was a 1:1 mole ratio between the iron used in the reaction and the copper formed as a product. This mole ratio result supports the hypothesis that iron is oxidized to the +2 state according to the following equation: \( \text{Fe(s)} + \text{CuSO}_4(\text{aq}) \rightarrow \text{Cu(s)} + \text{FeSO}_4(\text{aq}) \)

2. When you determined that the reaction was complete, had all of the iron metal reacted, or was some iron metal remaining in the beaker that had not reacted? Explain what observations support your answer. I observed that none of the original iron metal remained in the beaker. I could see that all of the silver-colored iron mesh had dissolved. The only solid present in the beaker was the reddish-brown flakes of copper that settled to the bottom of the beaker. I observed this to be copper because of its color.
3. When you determined that the reaction was complete, had all of the copper sulfate reacted, or was some copper sulfate remaining in the beaker that had not reacted? Explain what observations support your answer. I observed that copper sulfate still remained in the beaker because the solution still had a blue color even though the reaction had ended. The blue color indicated that there was still copper sulfate present that had not reacted.

4. Which reactant was the limiting reactant in this reaction? How do you know? The iron was the limiting reactant. I observed that all of the iron reacted because there was no iron left at the end of the reaction. The other reactant, copper sulfate, was still present in some amount because the solution still had a blue color.

5. Why did you weigh the paper + copper several times? It was important to make sure that all liquid had evaporated from the paper so that an accurate copper mass could be measured. By weighing it several times, I could see that the mass decreased until it became constant. Once the mass was constant, I could be confident that the sample was dry.

6. What changes could you make to the investigation so that you could perform it again without ending up with either excess iron or copper sulfate after the reaction is complete? I could use the amount of product formed during this investigation to calculate the amount of copper sulfate that actually reacted. I could repeat this investigation using that amount of copper sulfate.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test – changing only one variable at a time makes comparisons valid
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Balance
    - Erlenmeyer flask
    - Graduated cylinder
    - Filters
    - Funnel
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Touching (temperature, texture, shape, size, vibration, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns using:
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Comparing results to hypothesis
    - Answering the testable question

- **Patterns and Systems**
  - Patterns and Change
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Some small changes can be detected by taking measurements.
• Systems
  - Physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.

• Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
  - Scientific Data and Outcomes:
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - It is important in science to keep honest, clear, and accurate records.

• Scientific Endeavor
  - Characteristics of Science:
    - Scientific claims can be substantiated using data and observation.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Oxidation-Reduction Reactions

Overview

During redox reactions, electrons are transferred, leading to the reduction and oxidation of the chemicals involved. Tracking oxidation numbers of elements in compounds that participate in redox reactions shows which chemicals act as oxidizing and reducing agents. In this Exploration, students track oxidation numbers to identify the oxidizing and reducing agents in several redox reactions.

Student Learning Objectives

- Calculate the oxidation numbers of elements in the compounds participating in redox reactions.
- Identify the oxidizing and reducing agents in redox reactions by analyzing the change in oxidation numbers of elements.
- Analyze the role of oxidation numbers in determining the dynamics of redox reactions.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students select a reaction they want to analyze from the Select Reactants dropdown list. The complete reaction with the selected reactants is displayed. Random oxidation numbers are shown in spin boxes below the constituent elements of reactants and products. Students click the Increase and Decrease arrows to select the correct value of oxidation number in each spin box. They then use the Check button to validate their answers.

Students may use the Show Me! button to view the correct answer, if they are unable to assign oxidation numbers correctly. After identifying the correct oxidation numbers correctly, spin box will deactivate, while the spin boxes for incorrectly identified oxidation numbers will remain active for the student to make a correct selection. When all the oxidation numbers for the reactants are correctly identified, the students click answer buttons to identify the oxidizing and reducing agents for each of the reactions.

The students may use the Reset button to undo what they have done and select other reactants.

In the Tracker tab, the students review the correctly analyzed reactions and their oxidizing and reducing agents.
Answers to Questions in the Student Worksheet

1. Define redox reactions.
   
   **Answer:** Any reaction in which a group of atoms donates electrons and another accepts electrons to change oxidation numbers is termed as a redox reaction.

2. Differentiate between a reducing agent and an oxidizing agent.
   
   **Answer:** In a chemical reaction, the reactant that loses electrons is the reducing agent, whereas the one that gains electrons is the oxidizing agent.

3. List any two basic rules for assigning oxidation numbers to elements.
   
   **Answer:** Two of the basic rules for assigning oxidation numbers to elements include:
   a. The oxidation number of a free element is always 0.
   b. The sum of oxidation numbers of all the elements of a neutral compound is always 0.

4. Explain how oxidation numbers can be used to identify oxidizing and reducing agents in a chemical reaction.
   
   **Answer:** The oxidation number of an oxidizing agent decreases due to the redox reaction, whereas the oxidation number of a reducing agent increases during the redox reaction. This information can be used to identify oxidizing and reducing agents.

5. List the oxidation numbers of the constituent elements of Fe₂O₃.
   
   **Answer:** The oxidation number of iron in Fe₂O₃ is +3, whereas that of oxygen is -2.

6. Identify the oxidation number of chromium in CrO₃.
   
   **Answer:** The oxidation number of oxygen in a compound is -2. This value should be multiplied by 3 since there are three atoms of oxygen in CrO₃. To neutralize this value, the oxidation number of Cr must be +6 so that the sum of oxidation numbers of Cr and O is 0.

7. Identify the oxidizing agent in the following reaction:
   
   4Fe(s) + 3O₂(g) → 2FeO₃(s)
   
   **Answer:** Since the oxidation number of oxygen reduces from 0 to -2 in this reaction, it is the oxidizing agent.
8. Give an example of a redox reaction. Explain why it is a redox reaction.

   **Answer:** The reaction between ferric oxide and aluminum is a redox reaction since the oxidation number of aluminum decreases, whereas that of iron increases.

9. Explain why the study of redox reactions is important from the biological point of view.

   **Answer:** All biological processes such as respiration, osmoregulation, and digestion are redox reactions. The analysis of oxidation numbers can help us to analyze them better.

10. Describe a technique, other than those used in the Exploration, to identify oxidizing and reducing agents.

    **Answer:** The transfer of H+ ions and electrons can be used to identify the oxidizing and reducing agents in a chemical reaction.
Hands-On Activity
Reactivity Check

Objective:
In this activity, students will practice using the reactivity series to determine if reactions between specific elements will proceed.

Estimated time to complete: 10 minutes

Materials:
For each small group:
- Index cards

Procedure:
Have the students form groups of 2-4 students. Instruct students to create a table, similar to the Reactivity Series diagram in the Core Interactive Text, listing metals from high to low reactivity. Have students use this table as they play the game.

Have the students write each metal on an index card. Instruct the students to mix up the cards and place them face-down on a table. Have the first student flip a card and place it in the center of the table. Then, have each student flip one card in turn placing it in the proper sequence so that it corresponds with the reactivity series. Have them continue until all the cards have been flipped. As an extension, have students research different metals and add them to the set of cards.

Variation
Have students work in pairs and give each a set of “metal” cards. Each student should turn over a card; the “metal” that is higher on the reactivity series “wins” the hand. The student with the most hands won after all cards are turned wins the game.
Inquiry and Nature of Science Skills in this Activity:

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Applying a classification scheme to objects, substances, or organisms

- **Scientific Endeavor**
  - Characteristics of Science:
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Hands-On Activity
Redox Reaction Challenge

Objective:
In this activity, students will identify the half-reaction pairs that make up a variety of redox reactions, and use the half-reactions to write balanced equations.

Estimated time to complete: 20 minutes

Materials:
For each student:
• Redox Reactions Worksheet

Procedure:
Instruct students to balance the list of equations on the Redox Reactions Worksheet. They will find all the necessary oxidation and reduction half-reactions listed separately, in random order.

Instruct the students to first balance each redox equation using the following steps:

1. Identify the products and reactants.
   a. Write the unbalanced equation in ionic form, leaving out the spectator ions.
   b. Assign oxidation numbers, and identify the atoms that change their oxidation numbers.
2. Write and balance the half-reactions.
3. Combine the half reactions and make the electrons equal.

Then, students should find each half-reaction under the correct category (oxidation or reduction) and cross it off of the list.

Point out to students that the half-reactions in the list may not be balanced properly for the final equations, so coefficients might need to be added. When students have balanced all of the redox reactions in the list, there will be one oxidation and one reduction half-reaction remaining. The students should combine these to write a balanced equation for the final redox reaction.
Redox Reaction Worksheet

**Oxidation:**

- \(2\text{Cr}^{3+}(aq) + 7\text{H}_2\text{O}(l) \rightarrow \text{Cr}_2\text{O}_7^{2-}(aq) + 14\text{H}^+(aq) + 6e^-\)
- \(\text{Fe}^{2+}(aq) \rightarrow \text{Fe}^{3+}(aq) + e^-\)
- \(\text{Cu}(s) \rightarrow \text{Cu}^{2+}(aq) + e^-\)
- \(\text{Mg}(s) \rightarrow \text{Mg}^{2+}(aq) + 2e^-\)
- \(\text{Cu}(s) \rightarrow \text{Cu}^{2+}(aq) + 2e^-\)
- \(\text{Ag}(s) \rightarrow \text{Ag}^+(aq) + e^-\)
- \(\text{H}_2\text{O}_2(aq) \rightarrow \text{O}_2(g) + 2\text{H}^+(aq) + 2e^-\)
- \(\text{Cr}^{2+}(aq) \rightarrow \text{Cr}^{3+}(aq) + e^-\) 

**Reduction:**

- \(\text{Cu}^{2+}(aq) + 2e^- \rightarrow \text{Cu}(s)\)
- \(2\text{H}^+(aq) + 2e^- \rightarrow \text{H}_2(g)\)
- \(2\text{H}^+(aq) + \text{NO}_3^-(aq) + e^- \rightarrow \text{NO}_2(g) + \text{H}_2\text{O}(aq)\)
- \(\text{S}_4\text{O}_6^{2-} (aq) + 2e^- \rightarrow 2\text{S}_2\text{O}_3^{2-}(aq)\)
- \(2\text{Ag}^+(aq) + 2e^- \rightarrow 2\text{Ag}(s)\)
- \(5e^- + 8\text{H}^+(aq) + \text{MnO}_4^-(aq) \rightarrow \text{Mn}^{2+}(aq) + 4\text{H}_2\text{O}(l)\)
- \(\text{Cl}_2(g) + 2e^- \rightarrow 2\text{Cl}^-(aq)\)
- \(\text{O}_2(g) + 2\text{H}_2\text{O}(l) \rightarrow 4\text{OH}^- (aq)\)

Balance the following equations. Use the half-reactions above, crossing each one off as it is used.

1. \(\text{Zn}(s) + \text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g)\)

2. \(\text{Cu}^{2+}(aq) + \text{Mg}(s) \rightarrow \text{Mg}^{2+}(aq) + \text{Cu}(s)\)

3. \(\text{AgNO}_3(aq) + \text{Cu}(s) \rightarrow \text{Cu(NO}_3)_2(aq) + \text{Ag}(s)\)

4. \(\text{Cr}^{3+}(aq) + \text{Cl}_2(g) \rightarrow \text{Cr}_2\text{O}_7^{2-}(aq) + \text{Cl}^- (aq)\)
5. \( \text{S}_4\text{O}_6^{2-}(aq) + \text{Cr}^{2+}(aq) \rightarrow \text{Cr}^{3+}(aq) + \text{S}_2\text{O}_3^{2-}(aq) \)

6. \( \text{MnO}_4^{-}(aq) + \text{H}_2\text{O}_2(aq) \rightarrow \text{Mn}^{2+}(aq) + \text{O}_2(g) \)

7. \( \text{Ag}(s) + \text{CN}^{-}(aq) + \text{O}_2(g) \rightarrow \text{Ag(CN)}_2^{-}(aq) \)

8. \( \text{MnO}_4^{-}(aq) + \text{Fe}^{2+}(aq) \rightarrow \text{Mn}^{2+}(aq) + \text{Fe}^{3+}(aq) \)

9. Write the half-reactions not used above.
   oxidation half-reaction:
   
   reduction half-reaction:

10. From the pair of half-reactions, write the balanced equation for the redox reaction:
Redox Reactions Answer Sheet

1. Zn(s) + HCl(aq) \rightarrow ZnCl$_2$(aq) + H$_2$(g)
   Zn(s) + 2HCl(aq) \rightarrow ZnCl$_2$(aq) + H$_2$(g)

2. Cu$^{2+}$(aq) + Mg(s) \rightarrow Mg$^{2+}$(aq) + Cu(s)
   Cu$^{2+}$(aq) + Mg(s) \rightarrow Mg$^{2+}$(aq) + Cu(s)

3. AgNO$_3$(aq) + Cu(s) \rightarrow Cu(NO$_3$)$_2$(aq) + Ag(s)
   2AgNO$_3$(aq) + Cu(s) \rightarrow Cu(NO$_3$)$_2$(aq) + 2Ag(s)

4. Cr$^{3+}$(aq) + Cl$_2$(g) \rightarrow Cr$_2$O$_7^{2-}$(aq) + Cl$^-$ (aq)
   3Cl$_2$(g) + 2Cr$^{3+}$(aq) + 7H$_2$O(l) \rightarrow 6Cl$^-$(aq) + Cr$_2$O$_7^{2-}$(aq) + 14H$^+$ (aq)

5. S$_4$O$_6^{2-}$(aq) + Cr$^{2+}$(aq) \rightarrow Cr$^{3+}$(aq) + S$_2$O$_3^{2-}$(aq)
   S$_4$O$_6^{2-}$(aq) + 2Cr$^{2+}$(aq) \rightarrow 2Cr$^{3+}$(aq) + 2S$_2$O$_3^{2-}$(aq)

6. MnO$_4^-$ (aq) + H$_2$O$_2$(aq) \rightarrow Mn$^{2+}$(aq) + O$_2$(g)
   6H$^+$ (aq) + 2MnO$_4^-$ (aq) + 5H$_2$O$_2$(aq) \rightarrow 2Mn$^{2+}$(aq) + 5O$_2$(g) + 8H$_2$O(l)

7. Ag(s) + CN$^-$ (aq) + O$_2$(g) \rightarrow Ag(CN)$_2^-$ (aq)
   4Ag(s) + 8CN$^-$ (aq) + O$_2$(g) + 2H$_2$O(l) \rightarrow 4Ag(CN)$_2^-$ (aq) + 4OH$^-$ (aq)

8. MnO$_4^-$ (aq) + Fe$^{2+}$(aq) \rightarrow Mn$^{2+}$(aq) + Fe$^{3+}$(aq)
   8H$^+$ (aq) + MnO$_4^-$ (aq) + 5Fe$^{2+}$(aq) \rightarrow Mn$^{2+}$(aq) + 5Fe$^{3+}$(aq) + 4H$_2$O(l)

1. Write the half-reactions not used above.
   Oxidation half-reaction: Cu(s) \rightarrow Cu$^{2+}$(aq) + 2e$^-$
   Reduction half-reaction: 2H$^+$ (aq) + NO$_3^-$ (aq) + e$^- \rightarrow NO_2$(g) + H$_2$O(aq)

2. From the pair of half-reactions, write the balanced equation for the redox reaction:
   2NO$_3^-$ (aq) + Cu(s) + 4H$^+$ (aq) \rightarrow 2NO$_2$(g) + Cu$^{2+}$(aq) + 2H$_2$O(l)
Inquiry and Nature of Science Skills in this Activity:

- Interpret Data
  - Sort and classify using scientific reasoning by:
    - Applying a classification scheme to objects, substances or organisms
- Scientific Endeavor
  - Characteristics of Science:
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Hands-On Lab
Redox and Rust

Timing: one 90-minute class session

Objective(s):
In this experiment, students will explore the common reactions involved in the formation of rust. Students will develop a hypothesis regarding the corrosion of iron, and will test their hypothesis by using an indicator to determine if a redox reaction has occurred. The students will also explore how coatings on metal surfaces affect the rate of redox reactions.

Safety Precautions:
Remind the students that during the investigation, all directions must be followed. Students will be working with chemicals, so ensure that they do not eat or drink anything in the lab. Direct them to handle all chemicals with care. If any chemicals are spilled onto skin, have them report the incident to you immediately. Remind students to read all containers before using them, and have them tape the edges of the metal to prevent cuts. Make sure proper attire is always worn, including closed-toed shoes, eye protection, lab aprons, and gloves. After the lab is complete, instruct the students to dispose of all chemicals in a designated location.

Materials:
Per student:
- goggles
- lab apron

Per group of 2-3 students:
- beaker, 250 mL
- dropper
- graduated cylinder, 100 mL
- metal file
- 0.1 M potassium ferrocyanide solution (K₄Fe(CN)₆)
- 0.1 M potassium ferricyanide solution (K₃Fe(CN)₆)
- phenolphthalein indicator
- 0.1M sodium chloride (NaCl) solution
- steel, uncoated (nail or other object cleaned with steel wool)
- steel, polymer-coated (nail or other object coated with paint)
- watch glass
**Teacher Preparation:**
You may need to use steel wool to remove coatings from the nails to obtain uncoated steel. You also may need to paint some nails ahead of time to cover them with polymer seal. Make sure paint is dry before beginning lab.

Prepare the solutions needed as follows:

- **0.1M NaCl solution:** Dissolve 5.8 g NaCl per 1 L water
- **0.1 M K₄Fe(CN)₆ solution:** Dissolve 32.9 g of K₃Fe(CN)₆ per 1 L water
- **0.1 M K₄Fe(CN)₆ solution:** Dissolve 36.8 g K₄Fe(CN)₆ (anhydrous form) OR 42.2 g/L K₄Fe(CN)₆ ·₃H₂O per 1 L water
  
Prepare a copy of the Student Investigation Sheet for each student.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Before beginning the experiment, some background information may be necessary. Gather the students and describe how metals such as iron take part in oxidation-reduction reactions and that iron will oxidize to form rust. Describe that the rate of this reaction increases when water and salts are added.

Explain to students that the oxidation of iron takes several steps. First, pure iron is oxidized to form ions. Write the half-reaction for this step on the board:

\[ \text{Fe}(s) \rightarrow \text{Fe}^{2+}(aq) + 2e^- \]
Those ions are then oxidized further, and ions with a different charge are formed. Write the half-reaction for this step on the board:

\[ \text{Fe}^{2+}(aq) \rightarrow \text{Fe}^{3+}(aq) + e^- \]

The electrons from the oxidation reactions are used in a reduction reaction. Write the following on the board:

\[ \text{O}_2(g) + 2\text{H}_2\text{O}(l) + 4e^- \rightarrow 4\text{OH}^-(aq) \]

Make special note of the products of the above reactions, informing students that these will be important in the experiment.

Remind students that these reactions occur when electrons move from the metal to the oxygen. This electron movement is enhanced by the presence of a salt because the salt dissociates into ions, making the solution a conductor. Explain that this is why steel (made primarily of iron) rusts quickly in a salty environment. For example, a car has a greater tendency to rust if it is driven in a climate where salt is used to de-ice roads in the winter.

Explain that the products in the rusting process (\(\text{Fe}^{2+}\), \(\text{Fe}^{3+}\), and \(\text{OH}^-\)) can be observed by using indicators that change color upon reacting. Tell students that they will be using the following indicators:

- phenolphthalein, which turns pink in the presence of hydroxide ions (\(\text{OH}^-\))
- potassium ferrocyanide (\(\text{K}_4\text{Fe(CN)}_6\)), which turns a deep blue (precipitate) in the presence of \(\text{Fe}^{3+}\) ions (in the presence of \(\text{Fe}^{2+}\), a white precipitate may form)
- potassium ferricyanide (\(\text{K}_3\text{Fe(CN)}_6\)), which turns a deep blue (precipitate) in the presence of \(\text{Fe}^{2+}\) ions (in the presence of \(\text{Fe}^{3+}\), it will produce a brown solution)

Tell students that they will be testing different types of steel. (Remind the students that steel is composed primarily of iron.) One of the samples will be uncoated steel, another sample will be a scratched piece of uncoated steel, and the last sample of steel will be coated with a polymer.

After sharing the background information with the students, have them develop a hypothesis for this experiment. Possible examples include the following:

- The corrosion of steel occurs more rapidly when there is a scratch on the steel because there is more pure iron exposed than in the unscratched steel.
- The corrosion of steel occurs more rapidly on the uncoated steel because there is more pure iron exposed than in the coated steel.
Have students follow the procedure below.

**Preparation:**
1. Choose a method for recording and organizing your observations. Make sure to include space for all of the trials you will be completing.
2. Measure 100 mL of water using a graduated cylinder and pour it into a 250 mL beaker labeled “water.” Add 10 drops of phenolphthalein to the water in the beaker. Keep this solution to use in all three parts of the investigation.
3. Measure 100 mL of 0.1M NaCl solution using a graduated cylinder and pour the solution into a 250 mL beaker labeled “NaCl.” Add 10 drops of phenolphthalein to the solution in the beaker. Keep this solution to use in all three parts of the investigation.

**Part 1: Uncoated Steel**
1. Obtain a piece of uncoated steel.
2. Add four drops from the beaker labeled “water” to the steel’s surface. To a different area on the steel surface, add four drops from the beaker labeled “NaCl”.
3. Cover with a watch glass.
4. Record your initial observations in the table.
5. Observe any changes at 5 and 10 minutes and record your final observations in the table.
6. Add four drops from the beaker labeled “NaCl” to a different area on the steel’s surface.
7. Add 3 drops of 0.1 M K₃Fe(CN)₆ to the NaCl solution on the steel’s surface.
8. Cover with a watch glass.
9. Record your initial observations in the table.
10. Observe any changes at 5 and 10 minutes and record your final observations in the table.
11. Repeat steps 2-8, but instead use 3 drops of 0.1 M K₄Fe(CN)₆ for step 6.
12. Record your initial observations in the table.
13. Observe changes at 5 and 10 minutes and record your final observations in the table.

**Part 2: Scratched Steel**
1. Obtain a piece of uncoated steel.
2. Using the file, scrape the file against the surface of the steel, leaving a scratch down the center of the steel sample.
3. Add four drops from the beaker labeled “water” to the steel’s surface, making sure some liquid touches the scratched part. To a different area on the steel surface, add four drops from the beaker labeled “NaCl”, again making sure that this liquid also touches the scratched part.
4. Cover with a watch glass.
5. Record your initial observations in the table.
6. Observe any changes at 5 and 10 minutes and record your final observations in the table.
7. Add four drops from the beaker labeled “NaCl” to the steel’s surface, making sure some solution touches the scratched part.
8. Add 3 drops of 0.1 M K₃Fe(CN)₆ to the NaCl solution on the steel’s surface.
9. Cover with a watch glass.
10. Record your initial observations in the table.
11. Observe any changes at 5 and 10 minutes and record your final observations in the table.
12. Repeat steps 3-9 but instead use 3 drops of 0.1 M K₄Fe(CN)₆ for step 7.
13. Record your initial observations in the table.
14. Observe changes at 5 and 10 minutes and record your final observations in the table.

Part 3: Coated Steel
1. Obtain a piece of coated steel.
2. Add four drops from the beaker labeled “water” to the steel’s surface. To a different area on the steel surface, add four drops from the beaker labeled “NaCl”.
3. Cover with a watch glass.
4. Record your initial observations in the table.
5. Observe any changes at 5 and 10 minutes and record your final observations in the table.
6. Add four drops from the beaker labeled “NaCl” to the steel’s surface.
7. Add 3 drops of 0.1 M K₃Fe(CN)₆ to the NaCl solution on the steel’s surface.
8. Cover with a watch glass.
9. Record your initial observations in the table.
10. Observe any changes at 5 and 10 minutes and record your final observations in the table.
11. Repeat Steps 2-8 but instead use 3 drops of 0.1 M K₄Fe(CN)₆ for step 6.
12. Record your initial observations in the table.
13. Observe changes at 5 and 10 minutes and record your final observations in the table.

Guided Inquiry
Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:
• What is the redox reaction that occurs when salt and water are added to iron? (Solid iron is oxidized and oxygen gas is reduced.)
• What is the difference between K₄Fe(CN)₆ and K₃Fe(CN)₆? (the oxidation number of iron is +2 in the first compound, compared to +3 in the second)
• What conclusions can you make about the differences between the coated and the uncoated steel? Between scratched and unscratched steel? (It is easier to oxidize the iron of the uncoated steel and the scratched steel.)
• What color do you predict the phenolphthalein solution will turn when it comes in contact with the uncoated steel? The coated steel? (Pink and blue; however, the coated steel oxidation reaction should take longer than the uncoated steel oxidation reaction.)
Distribute the supplies to pairs or small groups. In their small groups, have students discuss the chemical reaction being studied. If necessary, explain the purpose of using phenolphthalein, potassium ferricyanide, and potassium ferrocyanide. This may also help direct students’ experimental designs.

Next, have students develop a hypothesis for this experiment. Possible examples include the following:

- *The corrosion of steel occurs more rapidly when there is a scratch on the steel because there is more solid iron exposed than in the unscratched steel.*
- *The corrosion of steel occurs more rapidly on the uncoated steel because there is more solid iron exposed than in the coated steel.*

After developing a hypothesis, have each small group design and write the procedure that they will follow to test their hypothesis. Have the students compare their ideas with other groups and revise as necessary. After each group has had you approve their plan, have them carry out their experiment.

Sample data table:

<table>
<thead>
<tr>
<th></th>
<th>Uncoated Steel</th>
<th>Scratched Steel</th>
<th>Coated Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time (min)</strong></td>
<td>0</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td><strong>Water</strong></td>
<td>colorless</td>
<td>colorless</td>
<td>colorless</td>
</tr>
<tr>
<td><strong>NaCl</strong></td>
<td>colorless</td>
<td>colorless</td>
<td>Slightly pink</td>
</tr>
<tr>
<td><strong>K₄Fe(CN)₆</strong></td>
<td>pink</td>
<td>pink</td>
<td>pink; blue precip.</td>
</tr>
<tr>
<td><strong>K₃Fe(CN)₆</strong></td>
<td>yellow</td>
<td>yellow</td>
<td>pink; blue precip.</td>
</tr>
</tbody>
</table>
**Analysis and Conclusions:**

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Why is either K₄Fe(CN)₆ or K₃Fe(CN)₆ added to the system during the investigation? Why is phenolphthalein added to the salt solution? *(Ferricyanide (K₃Fe(CN)₆) is red and turns blue when Fe²⁺ is present. Therefore, a blue precipitate shows that the redox reaction forming Fe²⁺ has occurred. Phenolphthalein indicates the presence of OH⁻ ions by turning pink. OH⁻ ions are present when the redox reaction occurs as the O₂ gas is reduced, enabling it to bond with hydrogen and form hydroxide ions.)*

2. What does this information about the oxidation of iron tell you about the different types of materials and coatings that are applied to steel? Are they useful or not? *(The coatings applied to steel prevent or slow the rusting of steel, making the coatings useful for a variety of applications. Steel may be a strong substance, but the large amount of iron in steel causes it to corrode quickly.)*

3. How do you think that the addition of salt to roads in the winter affects the corrosion of cars, bridges, and road structures made of steel? *(Salt increases the speed at which oxidation and reduction occur because it enables the electrons to move more easily throughout the system. Cars, bridges, and road structures that are made of steel tend to oxidize and therefore, corrode, much faster if salt is applied to the roadways in the winter.)*
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Control (control group) - used for comparison in which the independent variable is not changed
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Have as many details as possible replicated from the real thing
    - Function exactly like or similarly to the real thing
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use

- **Gather Data**
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Sketch
    - Photograph/image

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Developing a classification scheme for objects, substances or organisms
  - Identify and interpret patterns using:
    - Tables and graphs
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
• Communication in Science
  o Report results using:
    ▪ Written report
    ▪ Scientific illustration with proper labeling
    ▪ Table/graph showing data

• Scientific Investigation
  o Scientific Investigation:
    ▪ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    ▪ Scientific investigation leads to more questions.
    ▪ Scientific investigations lead to the development of scientific explanations.
  o Scientific Data and Outcomes:
    ▪ Accurate record keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
    ▪ It is important in science to keep honest, clear, and accurate records

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ Scientists are curious about how things work.
    ▪ One way to make sense of something is to think of how it relates to something more familiar.
    ▪ Scientific claims can be substantiated using data and observation.

• Engineering and Technology
  o Uses of Technology:
    ▪ Engineers, architects, and others who engage in design and technology use scientific knowledge to solve practical problems.
  o Societal Issues:
    ▪ Scientific discoveries have benefitted people in many ways.
Hands-On Activity
Copper Plating

Objective:
Students will construct and run a simple electrolytic cell to plate copper onto a galvanized nail.

Estimated time to complete: 10 minutes total (5 minutes for initial setup; 5 minutes for analysis)

Materials:
For each student pair:
- 600-mL beaker (1)
- 0.8 M CuSO₄ solution (350 mL)
- large galvanized nail, about 12 g (1)
- copper strip or copper wire (4 cm length) (1)
- wire, insulated with alligator clips (2)
- D cell battery (1)
- D cell battery holder (1)
- safety goggles (1 per student)

Procedure:
Organize students in pairs. Instruct students to wear safety goggles as they carry out this activity.

Direct students to set up an electrolytic cell that will plate copper metal on to a galvanized nail. The setup will take only five minutes. Then, the cell should be left undisturbed for 30 to 50 minutes while the electroplating takes place. It is best to have students set up the cell at the beginning of a class session, go on to other activities during the lesson, and then return to their cell later in the class period to finish up. The analysis portion will take only five minutes.

Instruct students to follow the steps below to set up their electrolytic cell:
1) Place 350 mL 0.8 M CuSO₄ into a 600-mL beaker (or similar sized container).
2) Insert the battery into the battery holder. Attach the wires onto each end of the battery holder.
3) Connect the alligator clip at the end of one wire onto the copper strip or wire. This is the positive pole of the battery. Connect the alligator clip at the end of the other wire onto the galvanized nail. This is the negative pole of the battery.
4) Insert both the copper strip and the nail into the copper sulfate solution, making sure the copper strip and the nail do not touch. They do not have to be totally submerged; the cell will run as long as a portion of each metal is in the solution.
5) Set aside the cell so that it remains undisturbed for 30 to 50 minutes.

After the cell has had a 30 to 50 minute incubation period, have students remove both pieces of metal from the copper sulfate solution and observe changes in the nail. They should observe shiny copper
metal covering the surface of the nail. If students do not observe this, the problem may be that the battery has run down, or that students did not set up their cell correctly to allow a complete circuit.

Ask students to think about the following questions as they observe the copper-plated nail:

- Where did the copper metal that covers the surface of the nail come from?
- Why did a battery have to be used for this process?
- What would have happened if the setup was repeated, but without the battery attached?
- Do you think a metal other than copper could be used to plate onto a nail?
- How do you think the mass of the nail changed as a result of being electroplated with copper?
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Study - compares changes in data points over time
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Identify and interpret patterns using:
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Formulating scientific explanations/arguments

**Nature of Science Standards**

- **Patterns and Systems**
  - **Patterns and Change:**
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    - Things that change may do so in steady, repetitive or irregular ways.
  - **Systems:**
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.

- **Scientific Investigation**
  - **Scientific Investigation:**
    - Scientific investigation leads to more questions.
    - Scientific investigations lead to the development of scientific explanations.
  - **Scientific Data and Outcomes:**
    - Collecting and analyzing data is the best way to understand a changing pattern.
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.

- **Scientific Endeavor**
o Characteristics of Science:
  ▪ Scientists are curious about how things work.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Electrochemistry

Overview

Students will make an electrochemical cell using different metal anodes and cathodes. They will observe the potential difference of the cell and calculate the electrode potential of one of the electrodes.

Student Learning Objectives

- Construct an electrochemical cell using different metal anodes and cathodes.
- Examine the movement of electrons within an electrochemical cell.
- Observe oxidation and reduction reactions occurring at the anode and the cathode.
- Determine the electrode potential of the cathode, anode, and the cell.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students make an electrochemical cell using different metal cathodes and anodes.

In the Explore tab, the students select a cathode and anode from the Metal Cathode and Metal Anode dropdown lists, respectively. Solutions in the anode and cathode beaker are displayed on the screen. Students switch on the battery using the Switch On button. They observe the flow of electrons through the circuit, the decomposition of the anode metal, and the deposition of the cathode metal. Note that no deposition takes place on a hydrogen cathode. The reactions occurring at the anode and cathode are displayed. The complete reaction of the cell is also displayed. Students use the Proceed button to calculate the cathode potential in the cell. They select the right answer from the answer buttons provided. Feedback is given based on the answer option selected.

Students may use the Reset button to change the cathode or anode metal and make a new cell.

In the Tracker tab, the students examine the various voltaic cells they have been created using different metal anodes and cathodes. They also compare the types of reaction, the electrode potentials, and the potential difference.
Answers to Questions in the Student Worksheet

1. Explain why a potential difference develops when the metals zinc and lead are used to make an electrochemical cell.

   **Answer:** Zinc has a greater tendency to lose electrons as compared to lead. This means that it has a higher oxidation potential. Thus, oxidation occurs at zinc and reduction at lead. This leads to the development of a potential difference.

2. Explain the importance of the salt bridge.

   **Answer:** The salt bridge prevents the two solutions from mixing and allows the movement of ions from one side of the cell to the other. The movement of the positively and negatively charged ions from the salt bridge prevents a build up of excess charge and restores charge balance in the beakers.

3. Describe the movement of electrons in an electrochemical cell.

   **Answer:** In an electrochemical cell, electrons move from the anode to the cathode. The electrons move through the external circuit and are involved in the reduction reaction.

4. Explain what an electrolyte is. Also explain why it is important in an electrochemical cell.

   **Answer:** The solution in which the metal strips or electrodes are dipped is known as the electrolyte. It is important as it completes the circuit for the electric current to flow through.

5. A standard electrode is a redox electrode which is used to build the scale for oxidation–reduction potentials. Its electrode potential is taken as zero. Which element used in this activity is the standard electrode?

   **Answer:** Hydrogen is used as a standard electrode.

6. The standard reduction potential of lithium, copper, and gold is -3.0401 V, 0.521 V, and 1.498 V respectively. Identify which of these elements will corrode most easily.

   **Answer:** Lithium will corrode most easily as it has the lowest standard reduction potential.

7. An electrochemical cell is made using a zinc strip dipped in zinc nitrate and a copper strip dipped in copper nitrate. Write the reactions occurring at the anode and cathode.

   **Answer:**
   
   Reaction at anode: \( \text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^- \)  
   Reaction at cathode: \( \text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu} \)
8. An electrochemical cell is made using a zinc strip dipped in zinc nitrate solution and a hydrogen strip dipped in hydrochloric acid solution. Write the complete redox reaction of the electrochemical cell.

   **Answer:** \( \text{Zn} + 2\text{H}^+ \rightarrow \text{Zn}^{2+} + \text{H}_2 \)

9. Use this Exploration to determine the cathode potential in the voltaic cell made up of a silver cathode and a zinc anode. The anode potential is 0.760 V. the cell potential is 1.550 V.

   **Answer:**
   \[
   E^0_{\text{cell}} = E^0_{\text{reduction}} - E^0_{\text{oxidation}}
   \]
   \[
   E^0_{\text{reduction}} = E^0_{\text{cell}} - E^0_{\text{oxidation}}
   \]
   \[
   = 1.550 - 0.760 \\
   = 0.790 \text{ V}
   \]

10. Use this Exploration to calculate the cell potential in the voltaic cell made up of a hydrogen cathode and lead anode.

   **Answer:**
   \[
   E^0_{\text{cell}} = E^0_{\text{reduction}} - E^0_{\text{oxidation}}
   \]
   \[
   = 0.126 + 0.00 \\
   = 0.126 \text{ V}
   \]
Overview: You will identify and write the meaning of examples of environmental print.

Directions:

1. Work with a partner to create a list of the examples of environmental print (such as symbols and labels) used in “Electrochemistry.”
2. In the chart below, draw a picture to represent each example of environmental print.
3. In the chart below, write the meaning.

What parts of the Techbook are you using? ______________________________

Who are you working with?

the whole class  a group  one other person  nobody

What will you have when you finish? ______________________________

Words to Know:

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
<tr>
<td>electrochemistry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>oxidation</td>
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<td></td>
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<tr>
<td>reduction</td>
<td></td>
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</tr>
</tbody>
</table>
Environmental Print Chart

<table>
<thead>
<tr>
<th>Example of Environmental Print</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>
Hands-On Lab
Making and Measuring Voltaic Cells

Timing: one 90-minute class session

Objective(s):
In this investigation, students set up a series of electrochemical cells using copper as one electrode and a second metal as the other electrode. Metals used include zinc, lead, and silver. Students then measure the voltages of each cell and use the information to develop a chart of reduction potentials for the metals.

Safety Precautions:
Students should wear safety goggles, lab apron, and closed-toed shoes during the lab. Students should be cautioned not to consume any materials used during the lab, and to wash their hands thoroughly at the conclusion of the activity.

Materials:
Per pair:
- beakers, 10 mL (5)
- electrodes made of Cu, Zn, Pb, Ag (individual pieces of metal 3 to 4 cm in length)
- emery paper
- filter paper, 4 cm × 6 cm (6 strips)
- medicine dropper
- voltmeter with wire leads, outfitted with alligator clips
- solutions:
  - 0.1 M copper(II) sulfate solution, CuSO₄ (10 mL)
  - 0.1 M lead(II) nitrate solution, Pb(NO₃)₂ (5 mL)
  - 0.1 M potassium nitrate solution, KNO₃ (10 mL)
  - 0.1 M silver nitrate solution, AgNO₃ (5 mL)
  - 0.1 M zinc sulfate solution, ZnSO₄ (10 mL)

Teacher Preparation:
- Use distilled or deionized water to make stock solutions and store in labeled brown bottles. Be sure to take into account the mass of water of hydration when preparing standard solutions. For example, ZnSO₄ comes as ZnSO₄•7H₂O; and CuSO₄ as CuSO₄•5H₂O.
- Cut pieces of metal and store in labeled jars.
- Check to be sure all voltmeters are working and replace any rundown batteries if needed.
- Prepare labeled waste containers.
- Prepare a copy of the Student Investigation Sheet for each student.
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Have students follow the procedure below to begin the investigation:
1. Clean one copper strip and one zinc strip with emery paper.
2. Obtain 5 mL 0.1 M CuSO$_4$ in a beaker. Obtain 5 mL ZnSO$_4$ in another beaker.
3. Place the zinc strip in the copper sulfate solution and the copper strip in the zinc sulfate solution. Observe both samples for at least two minutes to note any signs of reaction.
4. Determine whether either of these represents a spontaneous reaction.
5. Clean electrodes and store with other equipment.

Initiate a class discussion concerning the results. Ask students to describe any spontaneous reactions they observed (zinc metal in copper sulfate solution). Ask a student volunteer to come to the board to write equations for the two half-reactions describing this spontaneous reaction and the net reaction while the remainder of the class does the same at their desks. Then have the class review the work shown on the board and make any corrections they feel need to be made.

\[
\begin{align*}
\text{Oxidation half-reaction:} & \quad \text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^- \\
\text{Reduction half-reaction:} & \quad \text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}
\end{align*}
\]

Net reaction: \( \text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu} \)

Next, demonstrate how students can use three beakers, two strips of filter paper (folded lengthwise to 2 cm × 6 cm), and a voltmeter with leads to set up a voltaic cell. Do this by following the steps below:
1. Place 5 mL 0.1 M CuSO₄ in a beaker, 5 mL ZnSO₄ in another beaker, and 5 mL 0.1 M KNO₃ in a third beaker. Arrange the beakers in a line so that the beaker containing KNO₃ is in the middle.

2. Dip one end of a strip of filter paper into the KNO₃ beaker and the other end into the CuSO₄ beaker. Dip one end of a second strip of filter paper into the KNO₃ beaker and the other end into the ZnSO₄ beaker. Use the medicine dropper to add a few drops of KNO₃ solution to any sections of the filter paper strips that remain dry so as to moisten all parts of each strip.

3. Attach the wire leads to the voltmeter. Clip one lead to a strip of zinc using the alligator clip. Clip the other lead to a strip of copper using the alligator clip.

4. Place the copper strip into the beaker containing the copper sulfate solution and the zinc strip into the beaker containing the zinc sulfate solution.

5. Turn on the voltmeter. If you have correctly constructed the cell, the voltmeter should read +1.10 V. If the voltage reading is negative, switch the leads on the voltmeter. (If necessary, note to students that these are theoretical values obtained using 1 M solutions at exactly 25°C. Have students record their actual values, and as a class discuss the possible reasons for any discrepancies. These reasons might include the lower concentrations being used, differences in temperature, or other differences in conditions.)

6. Review with students that the sum of the electrical potentials of the half-reactions equals the total cell potential:

   Oxidation half-reaction: \( \text{Zn} \rightarrow \text{Zn}^{2+} + 2e^- \) \( \text{E}_{\text{ox}}=? \text{ V} \)

   Reduction half-reaction: \( \text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \) \( \text{E}_{\text{red}}=+0.34 \text{ V} \)

   Net reaction: \( \text{Zn} + \text{Cu}^{2+} \rightarrow \text{Zn}^{2+} + \text{Cu} \) \( \text{E}_{\text{cell}}=+1.10 \text{ V} \)

7. Ask students to determine the electric potential of the zinc oxidation half-reaction. (+0.76 V) Then ask students to tell you the zinc reduction potential and write out the reduction half-reaction. (−0.76 V; \( \text{Zn}^{2+} + 2e^- \rightarrow \text{Zn} \)) Use this opportunity to review the process of reversing the sign on the voltage when reversing the direction of a reaction.

8. Construct a chart on the board like the one below. Fill in the reduction potential for copper.
9. Instruct students to design experiments to fill in reduction potentials for the remaining metals: Zn, Pb, and Ag. Point out that they should order the reduction potentials from largest to smallest. Be sure they use the emery paper to expose fresh surfaces.

Guided Inquiry
Students should be able to use the basic setup of an electrochemical cell that you demonstrated during the Directed Inquiry segment to plan and construct a series of cells that will yield information about the reduction potentials of the remaining metals. Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- What will you use as a reference?
- What will you keep constant as you set up your experiments?
- What will you vary?

Students will need to set up at least two more electrochemical cells to explore the cells described below. If time constraints are an issue or if student observations are not providing accurate results, calculations could also be done to find the missing values. As an alternative, different groups of students could use different metals to build their cells, and all the groups’ results could be pooled.

1) Cu-Pb cell, which has the following half-reactions and total cell potential:
   Oxidation half-reaction:     \( \text{Pb} \rightarrow \text{Pb}^{2+} + 2\text{e}^- \) \( E_{\text{ox}} = \ ? \ V \)
   Reduction half-reaction:    \( \text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu} \) \( E_{\text{red}} = +0.34 \ V \)

   Net reaction:              \( \text{Pb} + \text{Cu}^{2+} \rightarrow \text{Pb}^{2+} + \text{Cu} \) \( E_{\text{cell}} = +0.47 \ V \)

2) Cu-Ag cell, which has the following half-reactions and total cell potential:
   Oxidation half-reaction:    \( \text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^- \) \( E_{\text{ox}} = -0.34 \ V \)
   Reduction half-reaction:    \( 2\text{Ag}^+ + 2\text{e}^- \rightarrow 2\text{Ag} \) \( E_{\text{red}} = \ ? \ V \)

   Net reaction:              \( 2\text{Ag}^+ + \text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{Ag} \) \( E_{\text{cell}} = +0.46 \ V \)
Sample table of results:

<table>
<thead>
<tr>
<th>Reduction half-reaction</th>
<th>$E_{\text{red}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Ag}^+ + e^- \rightarrow \text{Ag}$</td>
<td>+0.80 V</td>
</tr>
<tr>
<td>$\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$</td>
<td>+0.34 V</td>
</tr>
<tr>
<td>$\text{Pb}^{2+} + 2e^- \rightarrow \text{Pb}$</td>
<td>−0.13 V</td>
</tr>
<tr>
<td>$\text{Zn}^{2+} + 2e^- \rightarrow \text{Zn}$</td>
<td>−0.76 V</td>
</tr>
</tbody>
</table>

**Analysis and Conclusions:**

In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Which of the four metals is most easily oxidized and why? Which is least easily oxidized and why? Rank all four in order from most easily oxidized to least easily oxidized.

   Zinc is most easily oxidized because it has the lowest reduction potential and is least easily reduced.

   Silver is least easily oxidized because it has the highest reduction potential and is most easily reduced.

   Ease of oxidation: Zn>Pb>Cu>Ag

2. Write the half-reactions and net cell reaction for each electrochemical cell you constructed.

   **Cu-Pb cell:**
   
   Oxidation half-reaction: $\text{Pb} \rightarrow \text{Pb}^{2+} + 2e^- \quad E_{\text{ox}} = +0.13$ V
   
   Reduction half-reaction: $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \quad E_{\text{red}} = +0.34$ V
   
   Net reaction: $\text{Pb} + \text{Cu}^{2+} \rightarrow \text{Pb}^{2+} + \text{Cu} \quad E_{\text{cell}} = +0.47$ V

   **Cu-Ag cell:**
   
   Oxidation half-reaction: $\text{Cu} \rightarrow \text{Cu}^{2+} + 2e^- \quad E_{\text{ox}} = -0.34$ V
   
   Reduction half-reaction: $2\text{Ag}^+ + 2e^- \rightarrow \text{Ag} \quad E_{\text{red}} = +0.80$ V
   
   Net reaction: $2\text{Ag}^+ + \text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{Ag} \quad E_{\text{cell}} = +0.46$ V

3. What was the purpose of the potassium nitrate solution and filter paper strips in this experiment?

   These items served as a salt bridge between the two half-cells of each voltaic cell. The potassium ions and nitrate ions were able to move between the half-cells because the filter paper provided support for water and ions that connected the half-cells.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Recognize and develop testable questions that:
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
  - Choose appropriate tools to conduct an investigation:
    - Other Laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic
  - Identify and interpret patterns using:
    - Trends in data
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Reporting trends and patterns in the data
    - Formulating scientific explanations/arguments

- **Patterns and Systems**
  - Patterns and Change:
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
• Mathematical patterns help to predict future events and describe change in systems.

  o Systems:
    ▪ A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
    ▪ In some systems, it may not always be possible to predict accurately the result of changing some part or connection.
    ▪ As the complexity of any system increases, gaining an understanding of it depends on summaries, such as averages and ranges, and on descriptions of typical examples of that system.

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ Scientific investigations lead to the development of scientific explanations.

  o Scientific Data and Outcomes:
    ▪ Collecting and analyzing data is the best way to understand a changing pattern.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ Scientists are curious about wanting to know how things work.
    ▪ Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Exploration Teacher Guide: The Characteristics and Composition of the Atmosphere

Overview

The atmosphere consists of a mixture of gases. The concentrations of different gases present in the atmosphere are altered by human activities. In this Exploration, students use the Indoor Air Quality (IAQ) monitor to test the air quality in three different environments. They also identify the sources of various pollutants and the corrective measures that can be taken to reduce pollution or limit its effect.

Student Learning Objectives

- Understand how an Indoor Air Quality (IAQ) monitor is used to test and keep track of indoor air quality.
- Learn about the maximum acceptable indoor concentrations of carbon monoxide, carbon dioxide, and nitrogen dioxide.
- Examine the concentrations of pollutants in three different environments: forest (a control), home, and school.
- Identify sources of carbon monoxide, carbon dioxide, and nitrogen dioxide.
- Identify corrective measures that can be taken to reduce the pollution or limit the effect the pollution can have on people.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Apparatus tab, students understand how the Indoor Air Quality (IAQ) monitor works and how it is used to test and keep track of indoor air quality.

In the Explore tab, students select a pollutant using the radio button options in the Select Pollutant section. The three environments used in this Exploration are shown in the Selected Environment section. A forest environment is the standard environment used in this Exploration. It serves as a control where there is no indoor air pollution. At the beginning, Forest is selected in the Selected Environment section. Students use the Record button to record concentrations for the selected pollutant, over a period of 10 days, in the table and on the graph. Students use the Proceed button to compare the graph of the recorded concentrations in the forest environment with the maximum acceptable concentration for the selected pollutant.

Next, Home is selected in the Selected Environment section. Students use the Record button to record the concentration of the selected pollutant, over a period of 10 days, in the table and on the graph. They use the Proceed button to compare and analyze the graphs of the recorded concentrations.
concentrations in the home environment with those recorded in the forest environment and the maximum acceptable concentration for the selected pollutant. They use the radio button options to answer the questions and then use the Submit button to validate their selections.

Next, School is selected in the Selected Environment section. Students use the Record button to record concentrations for the selected pollutant, over a period of 10 days, in the table and the graph. They use the Proceed button to compare and analyze the graphs of the recorded concentrations in all three environments and the maximum acceptable concentration. They use the radio button options to answer the questions and then use the Submit button to validate their selections. Students then use the check boxes to identify the corrective measures that can be taken to decrease the concentration of the selected pollutant.

Students may use the Reset button to undo what they have done and examine another pollutant. They may use the View Pie Chart button to view a pie chart representing the general composition of Earth’s atmosphere.

In the Tracker tab, students track the pollutants for which they have recorded concentrations, over a period of 10 days, in the forest, home, or school environment. They may use the View Graph button to compare the graphs of the selected pollutant with its maximum acceptable concentrations.

**Answers to Questions in the Student Worksheet**

1. Identify the different gases that make up the atmosphere. What is the general concentration of each gas in the atmosphere?

   **Answer:** The atmosphere is a mixture of several gases in differing amounts. It consists of 78.08% of nitrogen (N₂), 20.95% of oxygen (O₂), 0.93 % of argon (Ar), 0.03% of carbon dioxide (CO₂), and 0.01% of other gases (such as methane, water vapor, helium, neon, and ozone).

2. Explain the importance of the atmosphere.

   **Answer:** The atmosphere is important because it is made up of gases like oxygen, carbon dioxide, nitrogen, and water vapor that are essential for life on Earth. In addition, the atmosphere protects living things from harmful ultraviolet radiation from the Sun, while allowing other wavelengths, which are the most important source of energy on Earth’s surface, to pass through. The atmosphere also acts as a blanket, keeping the planet warm, even during the night.

3. Identify the pollutants that can be detected using the IAQ monitor.

   **Answer:** The pollutants that can be detected using the IAQ monitor are carbon dioxide (CO₂), carbon monoxide (CO), nitrogen dioxide (NO₂), formaldehyde (HCHO), total volatile organic compounds (TVOCs), sulfur dioxide (SO₂), ammonia (NH₃), hydrogen sulfide (H₂S), and combustible gases.
4. Explain the adverse effects of nitrogen dioxide (NO₂), carbon monoxide (CO), and carbon dioxide (CO₂) on human health.

   **Answer:** Nitrogen dioxide (NO₂) irritates the respiratory tract and can cause severe damage to the lungs. Carbon monoxide (CO) causes tiredness, headaches, dizziness, nausea, and other flu-like symptoms. Exposure to carbon monoxide in high concentrations can be fatal. In high concentrations, carbon dioxide (CO₂) gas can affect the respiratory system and the nervous system. It can damage the eyes as it displaces oxygen. It can also cause unconsciousness as it restricts the amount of oxygen inhaled.

5. Identify two sources each of the following indoor air pollutants:
   a. Carbon monoxide (CO)
   b. Nitrogen dioxide (NO₂)

   **Answer:**
   a. The sources of carbon monoxide (CO) include unvented kerosene and gas space heaters, worn or poorly adjusted and maintained combustion devices (e.g., boilers, furnaces), gas water heaters, wood stoves, and fireplaces; gas stoves; generators and other gasoline powered equipment; automobile exhaust from attached garages; and tobacco smoke.
   b. The sources of nitrogen dioxide (NO₂) include kerosene heaters, un-vented gas stoves, and heaters.

6. List some human activities that cause an increase in the concentration of carbon dioxide (CO₂) in the atmosphere.

   **Answer:** Human activities like deforestation, burning fossil fuels, and land use changes like farming cause an increase in the concentrations of carbon dioxide (CO₂) in the atmosphere.

7. Why do you think it was important to measure pollution concentrations in a forest as well as indoors?

   **Answer:** It is important to have a control or standard of some sort in order to get an idea what the normal, unpolluted concentrations and variations in concentration might be.

8. Evaluate each of the following activities below in terms of how it affects the concentration of carbon monoxide in the air. If the activity has a negative effect on air quality, describe what should be done instead.

   a. Using proper fuel in kerosene space heaters.
b. Using a charcoal grill indoors.

c. Installing and use an exhaust fan, over gas stoves, vented to the outdoors.

d. Idling the car in a garage.

Answer:

a. Using proper fuel in kerosene space heaters helps maintain low levels of carbon monoxide and good air quality.

b. Burning charcoal releases potentially fatal carbon monoxide gas. Using them indoors increases carbon monoxide concentrations, degrades the indoor air quality, and can cause serious health problems and even death. Charcoal grills should never be used indoors.

c. Installing and use an exhaust fans helps maintain low levels of carbon monoxide and good air quality.

d. Idling a car in a garage releases potentially fatal carbon monoxide gas. You should never idle a car inside a garage.

9. Why do you think there are variations in CO, CO₂, and NO₂ in a forest, away from pollution sources? Are these gases considered pollutants when they are in a forest? Under what natural circumstances could the gases rise to dangerous levels?

Answer: There are natural sources of these gases. If the concentrations are not harmful and are not a result of human activities, they would not be considered pollutants. A forest fire could cause these gases to rise to dangerous levels.

10. What is the maximum acceptable concentration of the following pollutants in ppm?

   a. Carbon dioxide (CO₂)
   b. Carbon monoxide (CO)

Answer:

   a. The acceptable concentration of carbon dioxide (CO₂) is 800 ppm.
   b. The acceptable concentration of carbon monoxide (CO) is 9 ppm.

11. The maximum acceptable concentration of nitrogen dioxide is 0.1 ppm (parts per million). Calculate the acceptable concentration of nitrogen dioxide in parts per thousand (‰) and parts per hundred (%).
Answer:

1 ppm = 1/1,000,000 = 0.000001 = 1× 10^{-6}
1 ppt = 1/1,000 = 0.001= 1×10^{-3}
1 percent = 1/100 = 0.01 = 1× 10^{-2}

1 ppm= 10^{-3}‰
0.1ppm = 0.1×10^{-3}‰ = 10^{-4}‰ = 0.0001‰

1 ppm = 10^{-4}%
0.1 ppm = 0.1× 10^{-4}% = 10^{-6} % = 0.00001 %.

The acceptable concentration of nitrogen dioxide is 0.0001 parts per thousand or 0.00001 parts per hundred.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Lab
Modeling the Coriolis Effect

Timing: one 90-minute class session

Objective(s):
Students will perform kinesthetic activities that model the Coriolis effect. Students will also create, develop, and conduct investigations analyzing the Coriolis effect in an effort to gain a deeper understanding of this phenomenon.

Safety Precautions:
The most important safety concern is how to transport students to a park or a school playground to conduct the lab. If driving is necessary, provide officially approved transportation for students. Check with your school administration regarding school policies for field trips and familiarize your students with all such policies. Always monitor students to make sure they are wearing the necessary eye protection, as well as closed-toed shoes and clothing appropriate for each activity; if your class size is large, recruit proctors to help you monitor students. Bring along a first aid kit or bandages to treat simple abrasions and a whistle to quickly get students’ attention while outdoors.

Materials:
Per class:
• Several volleyballs (at least five or six)
• Access to a basketball court
• Access to a public park or a schoolyard playground that has swings and a merry-go-round
• Cameras or video equipment (if available)
• Student access to computers
• General lab and school supplies (e.g., turn tables, globes, string, tennis balls, protractors, funnels, etc.) that students might use in the Guided Inquiry

Teacher Preparation:
You will need to prearrange for the availability of a basketball court and a public park or a school playground with a set of swings and a merry-go-round. Also, you will need to prearrange for student transportation to the site(s). The day before teaching the lab, you will need to instruct students to dress appropriately for outdoor, physical activity.

Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success
of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**
Understanding the Coriolis effect by merely reading about it can be challenging. This is largely because the Coriolis effect involves rotational motion rather than simple linear motion. The Coriolis effect is more easily understood by performing activities and creating models. The first activity below is intended to help students understand simple linear motion. The next two activities are intended to help students understand rotational motion. If video equipment is available, you may wish to record these activities so that students can more easily analyze the movements of the balls.

**Understanding Simple Linear Motion**
1) Take the class to a basketball court and divide students into two large groups. One group will be called “runners” and the other group will be called “catchers.”
2) Instruct the “catchers” to line up at the center of the basketball court. The first catcher in line will stand in the exact center of the court and face the point where the half-court line intersects one of the sidelines. (See the diagram following step 4.) The remaining catchers will line up behind the first catcher.
3) Instruct the “runners” to line up at one of the corners of the basketball court and provide each of the runners with a volleyball.
4) Explain that each runner will run along the sideline from one corner of the court to the opposite corner. (Only one runner should run at a time.) Without breaking stride, the first runner will throw his or her volleyball sideways to the first catcher at center court as the runner immediately crosses the half court line. Also, explain that the runner will “attempt” to make the ball’s trajectory parallel to the half court line, as shown below:
5) Explain that each catcher will observe how successfully the corresponding runner was able to throw the volleyball parallel to the half court line. The catcher should specifically observe whether the runner’s motion deflected the volleyball away from the half court line, and in which direction. The catcher should then retrieve the volleyball and stand at the end of the runners’ line. After throwing the ball, the runner should stand at the end of the catchers’ line.

6) Repeat steps 4 and 5 until every student has performed once as both a runner and a catcher.

7) Ask students to analyze how a runner’s forward speed affected the trajectory of a volleyball as it was thrown sideways. (Most students should note that their forward momentum as a runner caused the ball to veer away from the catcher in the same direction as the runner’s movement.)

Understanding Rotational Motion, Part I
Next, take the class to a local public park or a schoolyard playground that has a set of swings and a merry-go-round. These next two activities are intended to help students understand rotational motion.

First, take the class to the set of swings. Divide the class into groups of 5 or more, depending on the number of available swings (one group per swing). Select one group for you to direct in a demonstration of the activity. Provide time for all groups to perform the same activity.

1) Instruct a pair of students to pass a volleyball back-and-forth in the following manner:
   Have one student use both hands to hold the volleyball at chin height. Then tell the student to pass the volleyball to his or her partner simply by flicking his or her wrists forward. (In other words, students should pass the ball by moving only their wrists, as though passing a basketball; the rest of their arms should not move. This will help to ensure the ball travels in a straight line when passed.) Tell the partner to pass the volleyball back to the original thrower in the same manner. Also, tell both students to note the path of the moving ball and try to make the trajectory as straight as possible (i.e., the ball should not veer to the left or right).

2) When the partners have successfully passed the ball several times, select one student to sit in a swing and lean backward with both arms fully outstretched behind the two chains (or cables) of the swing. To secure themselves to the swing while leaving their hands free to throw and catch, students should bend their arms forward at the elbows around the swing chains. Provide the student with a volleyball to hold with both hands under his or her chin, as illustrated below. Explain that the seated student should hold this position to ensure that he or she doesn’t fall out of the swing. This student will be designated as the “thrower.”
3) Instruct the remaining students in the demonstration group to stand in a circle around the student seated in the swing. These students will be designated as the “catchers.” Instruct the catchers to rotate the seated student so that the two chains of the swing wrap around each other like two strands of a rope. When the chains are sufficiently wound, have the catchers hold the thrower in that position until given the instruction to release; upon releasing the thrower, each catcher should take three large steps straight back. Explain that, upon releasing the thrower, he or she will spin around as the chains unwind.

4) When you are sure everyone understands the instructions, signal the catchers to release the thrower. (When they work in their groups, students should count together to three as a signal to release the thrower.) When all the catchers have stepped away from the thrower, instruct the thrower to pass the volleyball to one of the catchers while the thrower is spinning in the swing seat. (As explained in step 1, throwers should pass the ball by flicking their wrists forward, as though passing a basketball; the rest of their arms
should not move.) Also, instruct the thrower to continue to look straight forward after the ball is thrown to determine whether the ball’s trajectory is straight or whether the ball is deflected to the left or right.

5) When you are satisfied with the demonstration, direct the remaining student groups to repeat this activity in the available swings. (To be safe, groups should not work directly next to each other—leave a buffer of at least one swing between each group.) Provide enough time for everyone to participate as a thrower.

Understanding Rotational Motion, Part II

Take the class to the merry-go-round to perform this last activity.

1) Divide the class into two small groups and one large group. One of the small groups (2, 4, or 6 students, depending on the size of the merry-go-round) will be called “riders.” The other small group will be called “propellers” (2–3 students). The large group, consisting of the remaining students, will be called “catchers.”

2) Instruct the riders to seat themselves around the merry-go-round, facing inward; each rider should sit directly opposite another rider. Instruct riders to secure themselves to the merry-go-round in such a way that they can have both hands free to catch a ball. Take care to inspect that each rider can maintain both hands free and still not fall off the merry-go-round while it is moving. If they cannot maintain both hands free, then they should at least be able to maintain one free hand to deflect a thrown ball.

3) Instruct the propellers to position themselves around the merry-go-round. Explain that it will be their job to provide the propulsion for making the merry-go-round rotate.

4) Instruct the students in the catchers group to form a circle around the merry-go-round. Explain that it will be their job to catch and retrieve the volleyball for the riders.

5) Explain to the entire class that the rider with the volleyball will attempt to throw the ball (or roll the ball, if the merry-go-round is a solid disk) to the rider on the opposite side of the merry-go-round while it is rotating.

6) Instruct students to create hypotheses that relate the direction of deflection to the direction of rotation in the observational frames of reference for both riders and catchers. Then, explain to the entire class that the rider throwing (or rolling) the ball should try to observe whether the ball follows a straight path or is deflected after it is thrown (or rolled). Explain that the catchers also should try to observe whether the ball follows a straight path or whether the ball is deflected after it is thrown.

7) Also, explain to the entire class that the riders will need to take turns throwing the ball. The students in the riders group will need to switch places with students in the catchers group or the propellers group after every rider has thrown (or rolled) the ball at least twice.

8) Finally, provide one of the riders with a volleyball and begin the activity. Emphasize that the propellers should maintain no faster than a light jog while revolving the merry-go-
round, and be ready to stop the merry-go-round should the propellers begin to move at an unsafe speed. Provide enough time so that every student in the class has the opportunity to be a rider throwing the ball.

9) When students have completed the activity, have them compare their observations to their hypotheses and draw a conclusion about the relationship between direction of deflection and direction of rotation. *(Students should observe that the balls are deflected in the same direction that the throwers are rotating.)*

**Guided Inquiry**

Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Confirm that students have viewed the video segment *The Turning Earth* on the Discovery Education Web site. Be sure to point out to students that the final statement in this video is inaccurate: Hurricanes swirl counterclockwise—they do not have a “right-turning” swirl. Be sure that they have a generally good understanding of the basic principles of the Coriolis effect. Then, divide the class into groups of 5 or 6. Instruct groups to create and develop their own plans and procedures for modeling or illustrating the Coriolis effect. Prompt students to begin their investigations by suggesting a few possibilities. For example:

- Students could use a marble or felt-tipped pen to trace the path of a moving object in relation to a turntable as the table is rotated. An azimuthal map projection with the North Pole at the center could be placed on the turntable to provide additional opportunities for investigation. The video segment *The Global Picture: Air Currents* illustrates how this type of activity can be adapted using a rotating globe.
- A swiveling office chair and a wastebasket could be used to develop an activity that is similar to the second activity (playground swing) in the Directed Inquiry. For example, a student seated in the office chair could attempt to toss an item into the wastebasket as the chair is swiveled.
- Two furniture dollies connected by a long board that pivots on a central axis could be used to develop a “merry-go-round” with a greater diameter than the one in the third activity of the Directed Inquiry.
- Students could design an apparatus and develop a procedure to investigate whether the speed of rotation affects the apparent degree of deflection of a free-moving object.
- Students could design an investigation to determine whether the direction of deflected motion of a free-moving object differs as it moves from the perimeter to the center of a rotating system versus an object that moves from the center to the perimeter of the rotating system.
- Some students might want to research, design, and construct a Foucault pendulum to investigate Earth’s actual rotation. If time, materials, or scale become too limiting, then suggest that they develop a backup plan. For example, there are many Foucault pendulums in places such as universities, science museums, and planetariums. Students could investigate, photograph, and video a Foucault pendulum at one of these locations and deliver a report to the
class. The video segment *The Turning Earth* is a useful starting point to learn about Foucault pendulums.

- A video illustrating the Coriolis effect on a merry-go-round can be a very useful teaching tool. Some students might have the equipment, skills, and desire to produce such a video. If this is the case, encourage them to produce the video and show it to the class.
- Some students might think that the Coriolis effect always causes water to drain from sinks, wash basins, and toilets in a counterclockwise direction in the northern hemisphere. They could design an investigation, make observations, and collect data to determine whether this is true. If they analyze their data and conclude that this is not true, they could create a new hypothesis to determine why this is not true. [Note: Contrary to popular belief, the Coriolis effect does not cause water to drain clockwise or counterclockwise from a sink. The Coriolis effect caused by Earth’s rotation is minimal on this very small scale. In most everyday experiences (on the human scale), the Coriolis effect is so small that it is negligible and is only significant over vast regions of Earth’s surface. The shape of the sink, the initial velocity of the water, and other factors are usually more important in determining the direction of flow as water drains from a sink.]

Ask the students some guiding questions to help them focus their inquiry:
- What will be your objective?
- What question(s) would you like to pursue in your investigation?
- What will be the general plan or design of your investigation?
- What will be your step-by-step procedure?
- Do you foresee any problems or limitations that might interfere with your investigation?

Instruct students to write their objectives and general procedures on a piece of paper and submit them to you for approval. Explain that even the best developed procedures can encounter unanticipated problems. Instruct them to confer with you to reevaluate and adjust their procedures if necessary. After you have approved a group’s activity, instruct the group to proceed with its plan.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Does the rotational speed of a system affect the degree of deflection of a free-moving object within the system? Explain. Yes. If the system is not rotating, there is no deflection of the free-moving object. As the system rotates faster, the degree of deflection becomes greater.

2. Does the direction of deflection (i.e., to the left or to the right) differ for a free-moving object that moves inward toward the center of a rotating system versus an object that moves outward toward the perimeter of the system? Explain. No. If the direction of rotation remains the same (e.g., clockwise),
then the direction of deflection of the free-moving object also remains the same. For example, wind moving from the North Pole to the equator is deflected to the right. Wind moving in the opposite direction, from the equator to the North Pole, also is deflected to the right. This is because the air moving from the North Pole to the equator has less initial west-to-east velocity relative to the land it is moving toward. Air moving in the opposite direction, from the equator to the North Pole, has greater initial west-to-east velocity relative to the land it is moving toward.

3. A pen tip can be moved from the North Pole toward the equator along the arc bracket holding a globe. If the globe is rotated counterclockwise as the pen tip is moved along the arc bracket, then the pen mark will curve to the right (i.e., the correct direction). However, if the pen tip is moved along the arc bracket in the reverse direction (i.e., from the equator toward the North Pole), then the pen mark will curve to the left (i.e., the wrong direction). What procedure can be developed that properly demonstrates the Coriolis effect in this second situation? Explain. If a pen tip is moved along the arc bracket from the equator toward the North Pole, then the globe will need to be rotated clockwise (instead of counterclockwise) to get the correct curvature of the pen mark (i.e., to the right). Why? Initially, an object at the equator has a greater west-to-east velocity than locations farther north. In the model, the pen has no eastward velocity at any time. Rotating the globe in the clockwise direction adjusts for this difference in relative velocities.

4. How can a globe be used to demonstrate that a moving fluid curves to the right in the northern hemisphere and curves to the left in the southern hemisphere? A pen tip can be moved along the arc bracket from the North Pole toward the equator while the globe is rotated counterclockwise; the pen tip can then be moved along the arc bracket from the South Pole toward the equator while the globe is rotated clockwise. This will create a pen mark that curves to the right in the northern hemisphere and curves to the left in the southern hemisphere.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process
  - Develop predictions/hypotheses that:
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct field studies using:
    - Observational Study - compares changes in data points over time
    - Interventional Study - adjusts one or more elements and observes resulting changes over time
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated
    - Function exactly like or similarly to the real thing
    - Are based on logic and evidence
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation.

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Touching (temperature, texture, shape, size, vibration, motion)
    - Kinesthetic (balance, position)
  - Uses the appropriate format to record data:
    - Photograph/image
    - Video Recording

- **Interpret Data**
  - Identifies and interprets patterns:
    - Repeating physical or data patterns

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Formulating scientific explanations/arguments.

- **Communication in Science**
  - Report results using:
    - Peer presentation
    - Images or video
    - Formulating scientific explanations/arguments

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating a conclusion
    - Identifying alternative explanations
• Analyze scientific explanations
  • Patterns and Systems
    o Patterns and Change
      ▪ Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    o Systems:
      ▪ As the complexity of any system increases, gaining an understanding of it depends on summaries, such as averages and ranges, and on descriptions of typical examples of that system.
  • Scientific Investigation
    o Scientific Investigation:
      ▪ Science investigation begins with a testable question.
      ▪ New observations should be made when there is disagreement among initial observations.
      ▪ Science takes place in many locations including labs, offices, fields, and under the ocean.
      ▪ Scientific investigations generally work the same way in different places.
      ▪ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
      ▪ Scientific investigation leads to more questions.
      ▪ Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
      ▪ What people expect to observe can affect how they perceive what they observe.
      ▪ Scientific investigations lead to the development of scientific explanations.
Hands-On Lab
Analysis of a Saturated Salt Solution

Timing: One 90-minute class session

Objective(s):
Students will investigate the concentration of salt in a saturated solution.

Safety Precautions:
Remind students to follow all general lab safety rules, to wear closed-toe shoes, and not to eat or drink anything in the lab. Students should never leave the lab area unattended with chemicals sitting out. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for the disposal and cleaning of the chemicals and their containers. Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves. Instruct students to use the stirring rod and not the thermometer for stirring their solutions to avoid breaking the thermometer. Students should use protective gloves or tongs when handling hot objects. Advise students to keep flammable objects, such as clothing, long hair, and body parts away from the open flames.

Materials:
Per pair:
- potassium chloride, 40 g
- distilled water
- spatula
- 2 beakers, 250 mL
- stirring rod
- graduated cylinder, 100 mL
- thermometer
- glass funnel
- filter paper
- ring stand with ring
- volumetric pipet, 5 mL
- pipet bulb
- evaporating dish
- beaker, 400 mL
- boiling chips
- wire gauze
- Bunsen burner (hot plates may be used instead of Bunsen burners)
- finger cots or tongs
- balance
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
Teacher Preparation:

- Gather materials in advance of students performing the lab.
- Prepare a copy of the Student Investigation Sheet for each student.
- Prepare a copy of the procedure (shown below) for each pair of students.
- If possible, weigh one 40-gram batch of potassium chloride per pair in advance of lab. If this is not possible, have each pair weigh 40 grams of the salt prior to beginning the lab procedure.
- When students have completed the lab, they may discard their solutions in the sink.
- The solubility of potassium chloride in water at 25°C is 35.5 grams per 100 grams of water. The molar solubility of potassium chloride at 25°C is 4.66 M. Provide this information to students only after they have determined the molar concentration of their saturated solution experimentally.
- Hot plates may be used in place of Bunsen burners. If you are using hot plates modify the instruction accordingly.

Procedure

Set out materials at each student station. Instruct students to follow the directions below and to record their observations as they carry out each step of the procedure. Demonstrate how to use the volumetric pipet if students are not familiar with this technique. As students work, circulate around the room to observe their progress. You may want to ask students:

- Why is it important that there be undissolved salt in your solution before filtration? What is the purpose of the filtration step? Why is it important not to spill any of your solution during filtration and to wait until filtration is complete before moving to the next step? What are some events that could lead to error as you heat the salt over the Bunsen burner?

A. Preparation of a saturated salt solution

1. Transfer 100 mL distilled water into a 250 mL beaker using a graduated cylinder.
2. Gradually add small amounts of potassium chloride to the water as you stir using the stirring rod. Allow each salt addition to dissolve before adding more. Record your observations of the dissolution process as you make additions. Continue adding salt until salt no longer appears to dissolve. Stir the solution for an additional five minutes; then check to see that undissolved salt still remains. If the solution is clear and all salt has dissolved, add more solid salt and repeat the five minute stirring. Stop only when undissolved salt remains after five minutes of continuous stirring.
3. Set up a funnel in the ring of your ring stand by positioning it over a clean, dry 250 mL beaker. Line the funnel with filter paper. Filter your salt solution through the filter paper/funnel setup, collecting the filtered solution in the beaker. Measure the solution temperature.
B. Analysis of the saturated salt solution

1. Measure the mass of a clean, dry evaporating dish. Use a volumetric pipet to transfer 5.00 mL of the solution into the evaporating dish. Reweigh the dish and its contents.
2. Prepare a water bath by adding about 200 mL water to a 400 mL beaker. Add a few boiling chips to keep water boiling smoothly without bumping. Place the beaker on top of a wire gauze on the ring stand with a Bunsen burner underneath. The bottom of the beaker should be about 1 to 2 inches from the top of the Bunsen burner.
3. Place the evaporating dish containing your solution on top of the beaker of water. Light the Bunsen burner and position it under the beaker. Allow the heat from the water bath to evaporate the solution until liquid is no longer visible in the evaporating dish.
4. When you no longer see liquid in the dish, turn off the Bunsen burner. Allow it to cool for about 5 minutes and then use finger cots or tongs to move the evaporating dish onto a paper towel on the lab bench. Use extreme caution since the dish will still be very hot.
5. Use finger cots or tongs to carefully transfer the water bath to the lab bench. Be careful as the water will still be scalding hot.
6. Using finger cots or tongs, transfer the evaporating dish to the wire gauze on the ring stand. Light the Bunsen burner and heat the dish gently for two minutes with a low burner flame. This step will allow any final traces of water to evaporate from the sample.
7. When the salt appears to be completely dry, turn off the Bunsen burner. Allow the evaporating dish to cool completely.
8. Measure the mass of the completely cooled dish with salt.
9. Flush your salt solution and dried salt down the sink using plenty of water.
Analysis and Conclusions

1. Calculate the following using your experimental data:
   a. density of the solution in grams per milliliter
   b. concentration of the solution in grams of salt per liter of solution
   c. concentration of the solution in moles of salt per liter of solution

Sample answers:
volume of solution = 5.00 mL
mass of solution = 5.96 g
mass of salt = 1.53 g

a. density = \( \frac{\text{mass of solution in grams}}{\text{volume of solution in mL}} \)
   
   \[
   \text{density} = \frac{5.96 \, \text{g}}{5.00 \, \text{mL}} = 1.19 \, \text{g/mL}
   \]

b. concentration = \( \frac{\text{mass of salt in grams}}{\text{volume of solution in L}} \)
   
   \[
   \text{concentration} = \frac{1.53 \, \text{g}}{0.00500 \, \text{L}} = 306 \, \text{g/L}
   \]

c. concentration = \( \frac{\text{moles of salt}}{\text{volume of solution in L}} \)
   \( \frac{\text{mass of salt in grams}}{\text{molar mass of salt in grams/mole}} \)
   
   \[
   \text{concentration} = \frac{1.53 \, \text{g}}{74.55 \, \text{grams/mole}} \frac{74.55 \, \text{grams/mole}}{0.00500 \, \text{L}} = 4.11 \, \text{M}
   \]

2. After the filtration step, you measured the temperature of the filtered solution. Why was that important?

Since we were making a saturated solution, we needed to document the temperature at which the solution was made because the solubility of a solute in a solvent can vary depending on temperature. We needed to know the temperature in order to compare our results to the known value of molar solubility of potassium chloride at that temperature.

3. Obtain the molar solubility of potassium chloride from your teacher. How does your experimentally determined value for the molar solubility compare? What are some possible reasons for any differences?

Sample answer: The molar solubility of potassium chloride in water at 25°C is 4.66 M. Our experimentally determined molar solubility was 4.11 M at 26°C. Since the temperature of our solution was a bit higher than the temperature used to determine the actual value, we should have observed a higher molar solubility than 4.66 M. Instead, we observed a lower value. There are several possible reasons for this result. We may not have actually achieved saturation of our solution during its preparation. We also may have made a pipetting error.
and delivered less than the 5.00 mL volume into the evaporating dish. We also may have lost some salt during the heating step. We noticed that the salt spattered a bit when we heated it during the second heating step. Any loss of salt would have reduced the mass measured and used in our concentration calculations.

In this lab, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Design and conduct investigations using
    - fair test - changing only one variable at a time makes comparisons valid
    - independent variable - the one variable the investigator chooses to change
    - dependent variable - what changes as a result of, or in response to, the change in the independent variable
    - constant - identify variables that must remain unchanged
    - control (control group) - used for comparison in which the independent variable is not changed
  - Explain the investigative processes by
    - describing the logical sequence that was used to conduct the investigation
    - properly citing all equipment and materials
    - describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by
    - following lab safety procedures
    - recognizing safety equipment and materials and knowing their proper use
    - incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure
    - volume
    - mass
    - temperature
  - Choose appropriate tools to conduct an investigation
    - glassware (beakers, flasks, watch glass)
    - Bunsen burner
    - thermometer
    - balance
    - pipette
    - graduated cylinder
    - filters
    - evaporating dish
    - funnel
  - Use senses to observe
    - seeing (color, shape, size, texture, motion)
• Use the appropriate format to record data
  ▪ table
  ▪ writing (journal, worksheet, electronic text)

• Evaluate Evidence
  o Draw and support a conclusion by
    ▪ answering the testable question
    ▪ examining how investigations can be improved
    ▪ formulating scientific explanations/arguments

• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ When a scientific investigation is repeated, a similar result is expected.
    ▪ Scientific investigations generally work the same way in different places.
    ▪ Scientific investigations lead to the development of scientific explanations.
  o Scientific Data and Outcomes:
    ▪ Scientific claims are based on data and reliable scientific sources.
    ▪ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▪ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▪ Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
    ▪ It is important in science to keep honest, clear, and accurate records.

• Scientific Endeavor
  o Characteristics of Science:
    ▪ Science is based on factual knowledge.
    ▪ Scientific claims can be substantiated using data and observation.
    ▪ An important part of science is the critical review and analysis of any idea or conclusion.
Use the definitions of mass percent, volume percent, and parts per million to solve the problems below.

1. A solution was prepared by mixing 50.0 g MgSO₄ and 1000.0 mL water at 25.0°C. The density of the water at this temperature is 0.997 g/mL. What is the percent mass of MgSO₄ in this solution?
   [answer: 4.78%]

2. A student mixes 60.0 mL ethanol (C₂H₆O) with 240.0 mL water. Determine the concentration of this solution in volume percent.
   [answer: 20.0% ethanol by volume]

3. What is the concentration of a solution (in parts per million) if 15 mg KNO₃ are dissolved in water to make a total solution mass of 5.0 kg? [answer: 3.0 ppm KNO₃]
Use the equation \( \text{Molarity}_1 \times \text{Volume}_1 = \text{Molarity}_2 \times \text{Volume}_2 \) to solve the problems below.

1. What would the final volume be of a solution that was initially 3 liters of a 5 molar solution and ended up a dilution of 1.5 molar? [answer: 10L]

2. A chemist has 0.5 liters of 12 molar Sodium Hydroxide solution. How much water does she need to add to dilute the solution down to a 5 molar concentration? [answer: 0.7L]

3. If a chemist diluted a solution to produce 1.5 liters from an initial volume of 400 mL of a 6 molar solution, what will the resulting concentration be? [answer: 1.6M]
Calculating Dilutions

4.  700 mL of solution has a 2 molar concentration. How much water would it take to make this solution 0.75 molar? [answer: 1.87L]

5. A chemist mixed 2.5 liters of a dilution of .33 molar. If he initially started with 800 mL, what was the concentration of the original solution? [answer: 1.03M]
Use calorimetry to solve the problems below.

1. A calorimeter holds 105 g water at 21.0°C. A sample of hot iron is added to the water, and the final temperature of the water and iron is 28.0°C. What is the change in enthalpy associated with the change in the water's temperature? The specific heat of water is 4.18 J/(g°C).
   [answer: The enthalpy change is 3070 J.]

2. A 27.6 g sample of aluminum is warmed from 12.0°C to 45.4°C. If the specific heat of aluminum is 0.899 J/(g°C), what is the enthalpy change of the metal?
   [answer: The enthalpy change is 829 J.]

3. While fishing, a student leaves a 7.09 g lead sinker in the Sun. The sinker's temperature increases from 17.0°C to 30.0°C. If the specific heat of lead is 0.159 J/(g°C), what is the enthalpy change of the metal?
   [answer: The enthalpy change is 14.7 J.]

4. A student places 995 g water in a copper pot at 21.2°C. The pot has a mass of 635 g. The student then places the pot on a stove and begins heating it. If the final temperature of the water and copper is 95.0°C, what is the total enthalpy change of the system? The specific heat of water is 4.18 J/(g°C), and the specific heat of copper is 0.385 J/(g°C).
   [answer: The enthalpy change is 325,000 J.]
Hands-On Activity
Conductivity

Objective:
Students will use simple conductivity meters to explore the conductivity of several aqueous solutions.

Estimated time to complete: 15 minutes

Materials:
For each pair of students:
- homemade conductivity meter*
- small beakers or cups for making solutions (2)
- distilled (or deionized) water
- sodium chloride (table salt)
- sucrose (table sugar)
- plastic spoon
- stirring sticks

Procedure:
Students record observations in their notebooks as they carry out each step of this activity. To use the conductivity meter, begin by testing the meter to be sure that it works. Test the meter by touching the two paper clip ends to one another. The LED bulb should light up. To test the conductivity of a sample, touch both paper clip ends to the sample at the same time.

Before starting the tests, students should predict whether each solution will be conductive. Students should begin their tests by testing the conductivity of the distilled water sample. Students should then make a solution using a half spoonful of salt and distilled water, and test its conductivity. Next, students should make a similar solution using a half-spoonful of sugar and distilled water, and test its conductivity. Additional solutions or samples may be tested as desired.

As they make their observations, ask students to think about the following questions:
- What does a conductivity meter measure?
- Which sample has the greatest conductivity?
- Which sample has the least conductivity?
- Why did these samples have different conductivities?
- What would happen to the conductivity if you increased the amount of salt or sugar in the respective solutions? Why?
A homemade conductivity meter can be made using the following materials:

Materials for each meter:
- 9-volt battery
- paper clips (2)
- copper wire (3 pieces)
- LED bulb

Procedure: Unbend both paper clips so that they are straight. Connect the following in this order: paper clip, wire, LED, wire, battery, wire, paper clip. The LED should light if you touch the two paper clip ends together to complete the circuit.
Inquiry and Nature of Science Skills in this Activity:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process

- **Design Investigations**
  - Design and conduct investigations using:
    - Control (control group) – used for comparison in which the independent variable is not changed

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Conductivity
  - Choose appropriate tools to conduct an investigation:
    - Other laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Extrapolating results beyond the investigation
    - Formulating scientific explanations/arguments

- **Patterns and Systems**
  - Patterns and Change:
    - Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- **Scientific Investigation**
  - Scientific Investigation:
    - Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
• Collecting and analyzing data is the best way to understand a changing pattern.
  
  • Engineering and Technology
    o Uses of Technology:

Human beings have made tools and machines, such as x-rays, microscopes, and computers, to sense and do things that they could not otherwise sense or do at all, or as quickly, or as well.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g., x and y), trial number, or any type of data element (e.g., student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Concept: Solutions

Overview: You will create a chart to help increase your background knowledge about ideas in chemistry. You will use the chart to help make sense of written text.

Directions:

1. Before you read, create a list of the glossary words in the Explore section of “Solutions.” Use the Interactive Glossary to write the meanings of the glossary words.
2. Watch the videos “Solutions” and “Ionic Solutions” on your own. As you watch, use the graphic organizer to write down notes from the videos and ideas that you have about the information in the videos.
3. Discuss your notes with a partner. Use your partner’s ideas to help complete your chart.
4. Use the ideas in your chart to help make sense of the text as you read the Explore section of “Solutions.”

What parts of the Techbook are you using? _________________________________

Who are you working with?
the whole class  a group               one other person  nobody

What will you have when you finish? _________________________________

Words to Know:

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English Language Proficiency Activity

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Graphic Organizer:

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Discovery Education Science © Discovery Communications, LLC
Use equations for freezing point depression and boiling point elevation to solve the problems below.

1. A sample of glucose ($C_6H_{12}O_6$) of mass 8.44 grams is dissolved in 2.11 kg water. What is the freezing point of this solution? The freezing point depression constant, $K_f$, for water is 1.86 °C/mol.
   [answer: $-0.041°C$]

2. What is the boiling point of a solution made by dissolving 10.0 g sucrose ($C_{12}H_{22}O_{11}$) in 500.0 g carbon tetrachloride ($CCl_4$)? The boiling point of carbon tetrachloride is 76.5°C and the boiling point elevation constant, $K_b$, for carbon tetrachloride is 5.03°C/mol.
   [answer: 76.8°C]

3. Calculate and compare the freezing points of the following aqueous solutions: 0.0500 m CaCl$_2$ and 0.0500 m KCl. The freezing point depression constant, $K_f$, for water is 1.86 °C/mol.
   [answer: The freezing point of 0.050 m CaCl$_2$ is $-0.279°C$. The freezing point of 0.050 m KCl is $-0.186°C$, which is not as low as that of a calcium chloride solution of the same molality.]

4. Calculate the boiling point of a solution made by dissolving 0.01700 mol Na$_2$SO$_4$ in 100.0 g water. The boiling point elevation constant, $K_b$, for water is 0.5100°C/mol.
   [answer: boiling point of the solution is 100.3°C.]
Hands-On Lab
How Can We Purify Saltwater?

Timing: One 90-minute class session

Objective(s):
Students will practice the distillation process by removing salt from water.

Safety Precautions:
Do not use very strong acids or bases for this lab. Remind students to follow all general lab safety rules, to wear closed-toe shoes, and not to eat or drink anything in the lab. Students should never leave the lab area unattended with chemicals sitting out. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for disposal and cleaning of the chemicals and their containers. If using ammonia, students should work in a well-ventilated space and keep the ammonia at least one meter from their faces. Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

Materials:
Provide the following materials as per the diagram:

Per pair of students:
- conductivity meter
- safety goggles, one pair per student
- lab apron, one per student
- heat-resistant gloves, one pair per student
- 250 ml flat-bottomed flask
- test tube
- glass tube (10 cm) already inserted into a rubber stopper that fits the flat-bottomed flask
- glass tube (10 cm)
- rubber tubing to connect glass tubing (preassembled)
- 250 ml beaker
- retort stand and clamp
- hot plate
- beaker of sodium chloride solution
- 4–5 ice cubes

**Teacher Preparation:**
- Gather materials in advance of students performing the lab.
- Assemble the delivery tubes and stoppers.
- Combine salt with water to form a sodium chloride solution, representing seawater.
- Fill beakers with salt water.
- Obtain ice cubes 4–5 per group.
- Set up Bunsen burners or other heating elements at each station, along with the components of the distillers.
- Be prepared to review why the lack of drinkable water is a problem, even though Earth has such a large amount of water.

**Procedure**

Inform students that they will be assembling a distiller out of the components at their lab station, and using it to solve a real-world problem by distilling freshwater from salt water.

1. Have students begin by using the conductivity meter to test the salinity of the water in the beaker. Instruct students to write down their observations on the Student Investigation Sheet.
2. Observe students as they follow this procedure for constructing a distiller:
   a. Pour 50 ml of sodium chloride solution into the flat bottomed flask. Insert the stopper with the tubing into the flat bottomed flask.
   b. Assemble the remaining apparatus as shown.
   c. Insert the other end of the tubing into the test tube in the iced water.
3. Have students turn on their hot plate to 120 degrees Celsius (a burner, a tripod, and gauze could also be used).
4. Tell students to observe the movement of the water vapor through the distillation materials. While the water is distilling, have them write their thoughts and observations on the student sheet. Ask: What do you think will be the result of the experiment?
5. At the end of the lab, have students wait until their apparatus has cooled. Once cooled use the conductivity meter to test the water collected in the test tube and any water left in the round bottomed flask. If there is no liquid left in the round bottomed flask, have them observe the solids that remain in the beaker.

**Analysis and Conclusions**

1. How does the original water compare to the water collected in the distillation process? How does it compare to the water or solids left in the beaker at the end of the distillation process? **Sample answer:** The original water is more saline and more conductive than the water collected, but less saline and less conductive than the water left in the beaker.
2. Do you think distillation is a useful method for removing salt from water? Why or why not? **Sample answer:** Yes, because water has a much lower vapor point than salt, so the water can be easily distilled and collected.
3. Distillation is not the only method used to remove contaminants from water. Based on what you have learned about separating mixtures, what other contaminants could be removed by distillation? What contaminants would need another method? **Sample answer:** Contaminants with much higher or much lower vapor points could be easily separated from water. Contaminants with vapor points close to water’s would need another method.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Recognize and develop testable questions that
    - can be answered with a science investigation or observational study

- **Design Investigations**
  - Practice lab safety by
    - following lab safety procedures
    - recognizing safety equipment and materials and knowing their proper use

- **Evaluate Evidence**
  - Draw and support a conclusion by
    - using data to determine the cause effect relationship observed in the investigation
    - articulating a conclusion that is based on evidence and that answers a testable question
    - describing how evidence gathered supports a conclusion
    - drawing a conclusion that incorporates prior knowledge
Hands-On Lab
Investigating Chromatography: Hidden Colors

Timing: One 50-minute class session

Objective(s):
Students will investigate chromatography by separating ink mixtures into their component colors.

Safety Precautions:
Do not use very strong acids or bases for this lab. Remind students to follow all general lab safety rules, to wear closed-toe shoes, and not to eat or drink anything in the lab. Students should never leave the lab area unattended with chemicals sitting out. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for disposal and cleaning of the chemicals and their containers. If using ammonia, students should work in a well-ventilated space and keep the ammonia at least one meter from their faces. Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

Materials:
Per pair of students:
- beaker of water
- beaker of rubbing alcohol
- strips of filter paper (dimensions)
- water-soluble markers in a variety of colors
- one black marker
- at least one permanent marker
- small container of ink
- 2 clear 250 ml beakers
- 2 pencils
- ruler
- roll of sticky tape
- paper towels
- 2 sheets of plain white paper
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
**Teacher Preparation:**
- Gather materials in advance of students performing the lab.
- Cut strips of filter paper that are about the same length as the height of the plastic cups. Give each student two strips for each of their markers/ink sources and keep a number of extras in case of mistakes.
- Test the markers/ink sources prior to the lab to make sure you know what result you will get from each sample.
- Make sure students have a variety of markers/ink sources.

**Procedure**

1. Have students pour 1.5 cm of water into one cup, and 1.5 cm of rubbing alcohol into the other. Instruct students to label each cup with its solvent.
2. Have students measure 2 cm from one end of each piece of filter paper, and mark it with a pencil. Then, have them take their markers and ink, and make a dot on two strips of filter paper with each marker at the 2-cm mark. Be sure to explain to students that they are doing this because the dot must not touch the liquid, so it must be higher than the level of the liquid.
3. Have students tape the two sets of filter paper strips to the two pencils. Then, have them place one pencil across the top of the water cup and the other across the top of the alcohol cup. Make sure their paper touches the liquid, but the ink dots do not. Provide spare strips if needed.
4. Tell students to observe the effects of the liquids on the ink marks. Have them record their observations in the Student Investigation Sheet. In particular, students should note any differences between the strips in water and the strips in alcohol.
5. Once the ink mixtures have separated, have the students remove the strips from the cups and rest them on the paper towels to dry. Then, have students tape the strips to the 2 pieces of white paper, and label them with “water” or “alcohol”, as well as the original color of the ink or marker.

**Analysis and Conclusions**

1. What new information did you learn about each mixture by separating it? Sample answer: I learned how many components were in each mixture because the components appeared at different spots on the filter paper.
2. What did you notice about the patterns of color separation? What explanation can you give for your observations? Sample answer: The patterns were different in water and alcohol. This could be because each color had different affinity for the two solvents and different affinity for the filter paper.
3. Why do you think certain colors climbed higher on the filter paper than other colors? Sample answer: Different colors have different chemical compositions, so they have different solubilities. The more soluble the component, the higher it climbs on the filter paper.
4. Scientists use chromatography to analyze mixtures, identify their components, and quantify how much of each component makes up the mixtures. How could this kind of analysis be useful? Answers will vary. Sample answer: Chromatography can be used to identify the chemical components of a sample. This can be useful in science, such as forensics. It can also be useful for testing samples for chemicals, like blood testing or environmental testing.
5. Suggest how you could use chromatography to obtain a pure sample of a substance from a solution that contains many solvents. Sample answer: Chromatography can be used to separate the different solvents in a solution, leaving behind a pure sample of the desired substance.

In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Recognize and develop testable questions that
    - specify a cause-effect relationship
    - can be answered with a science investigation or observational study

- **Design Investigations**
  - Explain the investigative process by
    - properly citing all equipment and materials
    - describing it so that it can be easily repeated by a fellow scientist

- **Gather Data**
  - Use senses to observe:
    - seeing (color, shape, size, texture, motion)

- **Interpret Data**
  - Identify and interpret patterns:
    - repeating physical or data pattern
    - analyzing data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by
    - using data to determine the cause effect relationship observed in the investigation
    - articulating a conclusion that is based on evidence and that answers a testable question
    - describing how evidence gathered supports a conclusion
    - drawing a conclusion that incorporates prior knowledge
Investigating the Solubility of a Salt

Timing: one 90-minute class session

Objective(s):
In this investigation, students make a series of aqueous sodium nitrate solutions of varying concentrations. All solutions are heated so that the salt dissolves, and then the solutions are allowed to cool. As the solutions cool, students observe the temperature at which the salt crystallizes. A temperature probe may be used to collect data electronically. This process provides students with the maximum solubility of sodium nitrate at various temperatures. As part of the investigation, students will develop a hypothesis about temperature and salt solubility, produce a graph, and learn analytical laboratory skills. If desired, graphing can be done using a graphing calculator or graphing program connected to the probeware.

Safety Precautions:
Students should be cautioned that they will be using a Bunsen burner to make a hot water bath. Students should be instructed in the safe operation of a Bunsen burner and in the safe handling of hot glassware. An example experimental setup should be provided and discussed before students begin work so that they can see the correct placement of the water bath over the Bunsen burner. Long hair should be tied back, and students should wear safety goggles, lab aprons, and closed-toe shoes during the lab.

Materials:
Per pair of students:
- beaker (250 mL)
- clock or watch
- graduated cylinder, 10 mL
- ice
- iron ring and ring stand
- (optional) if using probeware, a separate stand with a clamp to hold the temperature probe
- sodium nitrate (50 g)
- spatula
- stirring rod
- test tubes (5)
- test tube holder
- test tube rack
- thermometer (0°C –100°C) or probeware with temperature probe
- (optional) graphing calculator or computer graphing program with interface needed to connect to probe
- water, deionized or distilled
- wax pencil (or other marker for labeling test tubes)
- wire gauze
- goggles
- lab apron

Per class:
- electronic balance

Teacher Preparation:
- Prepare a sodium nitrate sample for each class demonstration. Measure 14.00 g NaNO₃ into a test tube. Measure 10 mL distilled or deionized water in a graduated cylinder.
- Prepare a hot water bath (80°C –100°C) using the 250-mL beaker, tap water, ring stand, iron ring, wire gauze, and Bunsen burner. Be sure that the ring is adjusted so that it is about 2–3 cm above the top of the Bunsen burner.
- Prepare a copy of the Student Investigation Sheet for each student.
- If you choose to use probeware and graphing calculators or programs for this investigation, take time to become familiar with the technology beforehand. Read the instructions provided and be prepared to explain the use of the equipment to the class.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry
1. Begin by asking a student to describe an ionic solid and explain what happens when it dissolves in water. Ask the class to fill in any additional information that the student may have omitted. Continue the discussion until you feel satisfied that the process has been correctly summarized. (An ionic salt contains both positively charged and negatively charged ions that are packed together in a crystal. When it dissolves, the crystal is disrupted and each individual ion breaks away from the solid to become surrounded by water molecules.)
2. Write the formula NaNO\(_3\) on the board. Explain to the class that they will be working with this ionic solid to determine its solubility at various temperatures. Ask a volunteer to define solubility (the maximum amount of a solute that dissolves in a specified amount of solvent under specified conditions).

3. Tell students that you will demonstrate a method for determining the solubility of sodium nitrate. Be sure to wear safety goggles and exercise proper safety procedures as you conduct the demonstration.

4. Explain that you measured 14.00 grams of sodium nitrate into a test tube before class. Show the sample that you measured. Explain that you will add exactly 10.0 mL of water to this sample, and then add the water from the graduated cylinder that you prepared earlier. Using the test tube holder to hold the test tube, place the test tube in the hot water bath. Stir the solution with a stirring rod until the sodium nitrate has completely dissolved.

5. Remove the stirring rod and place a thermometer or temperature probe into the solution. If using a temperature probe, make sure the wire does not come near the flame. You may need to clamp it to the stand. Allow the temperature to stabilize (about 1 minute) and then remove the test tube from the hot water bath and place it in the test tube rack. Ask a student to come up and observe the temperature and the solution. Make a two-column data table on the board with the headings “Temperature” and “Solution Observations.” Enter the information supplied by the student in the data table. Since most of this data will not be used in the final graph, you do not need to input this data into the graphing calculator or graphing program if one is being used.

6. Ask the student to continue observing the solution as it cools, and record temperature observations periodically. Observations do not need to be made according to any specific time interval; simply make a few periodic observations. Eventually, the solution will cool to a temperature at which the sodium nitrate will begin to crystallize. The student should note this temperature. (Crystallization should occur at about 73°C.) Record this information on the data table, or if using a graphing program, input it into the program. At this point, show students how to set up the graphing calculator or graphing program to accept data from the temperature probe.

7. Ask the class what the crystallization event signifies about the solution. If they struggle, remind them that solubility is defined as the maximum amount of a solute that dissolves in a specified amount of solvent under specified conditions. (Before crystallization, all of the sodium nitrate was soluble in the water. As the solution cooled, the solubility decreased. Crystallization signifies that not all of the sodium nitrate is soluble any longer. It reached its solubility maximum and then exceeded the maximum to crystallize out of solution.)

8. Write the temperature at which crystallization occurred on the board. Also write the mass of the sodium nitrate sample (14.00 g) and the volume of water (10.0 mL) on the board. Ask students what these numbers tell them about the solubility of sodium nitrate in water. (At 73.0°C, sodium nitrate’s solubility is 14.00 g NaNO\(_3\) per 10.0 mL water.)

9. Draw a set of axes on the board to show a graph. Write “NaNO\(_3\) Solubility (grams/10.0 mL water)” on the y-axis and “Temperature (°C)” on the x-axis. Ask students how the data collected so far can be used to fill out the graph. (We have only one point for the graph so far.)
10. Tell students that they will design a larger investigation to explore the effect of temperature on solubility of sodium nitrate. They will generate a complete graph of solubility versus temperature using their own data by the end of the investigation. If probeware and graphing calculators or programs are being used, tell students that their graph will be generated by the program.

11. Give students time to use what they observed in your demonstration to plan the rest of their investigation. Ask:
   - How many samples will you prepare?
   - How will the samples differ?
   - What will you keep constant?

12. Have students carry out their investigations and record and graph their data. A sample procedure is provided after the Guided Inquiry instructions.

Guided Inquiry
Instead of performing a demonstration, you may choose to have students plan how to set up their own investigations, develop their own procedures, and decide how to collect, record, and graph their data. In this case, provide students with the option of using thermometers and graphing by hand, or using probeware and graphing calculators or graphing programs. Allow students to choose their own equipment and technology. Ask some guiding questions to help students focus their inquiry:
   - What question are you investigating? What do you predict the answer will be?
   - How can you collect the data you need to plot a graph of solubility (saturation point) versus temperature?
   - How many solutions will you prepare?
   - How will you identify the saturation point for each solution?
   - How will the solutions differ?
   - What will you keep constant?
   - How will you select the equipment and technology you will use to collect data?
   - How will you record data?
   - How will you graph data?

1. Explain the proper setup of water baths. Explain the safe operation of Bunsen burners.
2. Instruct students to construct a hypothesis concerning the effect of temperature on sodium nitrate solubility.
3. Instruct students to develop a question, a hypothesis, and a plan for carrying out their investigation. Allow students to choose their own equipment and technology. Remind them that they need to have your approval of their plan before they begin any lab work. As part of their plan, students should construct any data tables they will need as they carry out their plan. They should also have a plan for graphing their data.
Sample data:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass of NaNO₃ (g)</th>
<th>Volume of Water (mL)</th>
<th>Temperature of Crystallization (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.0</td>
<td>10.0</td>
<td>did not crystallize even at the lowest temperature, 8.0°C</td>
</tr>
<tr>
<td>2</td>
<td>8.0</td>
<td>10.0</td>
<td>9.5°C</td>
</tr>
<tr>
<td>3</td>
<td>10.00</td>
<td>10.0</td>
<td>34.5°C</td>
</tr>
<tr>
<td>4</td>
<td>12.00</td>
<td>10.0</td>
<td>54.0°C</td>
</tr>
<tr>
<td>5</td>
<td>14.00</td>
<td>10.0</td>
<td>72.5°C</td>
</tr>
</tbody>
</table>

The students’ graphs should show that the solubility of sodium nitrate increases as the temperature increases.
Sample Procedure for Directed Inquiry

1. Prepare five solutions of NaNO₃. Use the electronic balance to measure each mass of solid and place it in a test tube. For example, measure 6 g, 8 g, 10 g, 12 g, and 14 g of NaNO₃ into five test tubes. Label each test tube.

2. Use the graduated cylinder to add 10.0 mL of distilled water to each test tube.

3. If you are using probeware and a graphing calculator or program, set it up as instructed by your teacher.

4. Set up your hot water bath as follows: Set up the ring stand and iron ring, and place the wire gauze on the ring. Adjust the ring so that it is about 2 to 3 cm above the top of the Bunsen burner. Fill the 250 mL beaker a bit more than half full of water, and place it on the wire gauze. Light the Bunsen burner. Your hot water bath should be around 80°C – 100°C for this investigation. Check the temperature of the water bath every few minutes as needed.

5. Using the test tube holder to hold the test tube, place the first test tube in the hot water bath. Stir the solution with a stirring rod until the solute has completely dissolved.

6. Remove the stirring rod and place a thermometer or temperature probe into the solution. Make sure the wire of the probe does not come near the flame. Let the temperature stabilize for about 1 minute. Remove the thermometer or probe, take the test tube from the hot water bath, and put it in the test tube rack. Put the thermometer or probe back in the test tube and start monitoring temperature, but do not yet record any data.

7. Eventually, the solution will cool enough so that solid will begin to precipitate out. Record the temperature as soon as you see this happen. If using a temperature probe, collect the first data at this point.

8. Repeat steps 5 to 7 for each solution.

9. When you are finished collecting data, prepare your graph either by hand or electronically.
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What question were you investigating, and what was your hypothesis?
   **Sample Response:** We were investigating the relationship between solubility of sodium nitrate and temperature. My hypothesis was that solubility would increase as the temperature increased.

2. Do your results support your hypothesis? Explain.
   **Sample Response:** Yes, we hypothesized that the solubility of sodium nitrate would decrease as temperature decreased. We did not find a straight line on our graph, but the trend showed a definite decreasing solubility with colder temperatures.

3. What equipment and technology did you select for your investigation, and why did you choose it?
   **Sample Response:** For example, we used 250 mL beakers to make each solution because we wanted 100 mL solutions to make our calculations easier. We used graduated cylinders to measure volume, and an electronic balance to measure mass, because these were our only options. We used a temperature probe, interface, and graphing program to collect and graph our data, because that seemed like the most accurate way to do it. We made our solutions using sodium nitrate and distilled water. We used distilled water to make sure the solutions contained only sodium nitrate and no other ions.

4. Compare your graph with graphs generated by other student groups. Are they the same or do they differ? Would you expect the graphs to be the same? Explain.
   **Sample Response:** Yes, our graph looks very similar to other graphs. We used different masses of sodium nitrate, but the final lines that we drew ended up connecting all of these data points in the same way. I would expect that the graphs would be the same because we are investigating an intensive property of sodium nitrate. The solubility of sodium nitrate is constant and unchanging, so we all should get the same results as long as we use good experimental procedures and techniques.

5. If you investigated a different ionic solid such as potassium nitrate, KNO₃, would you expect the same results? Explain.
   **Sample Response:** In general, I would expect to see a decrease in solubility of KNO₃ with temperature like those we saw for NaNO₃. However, since we would be using a different substance, the lines would probably not overlap. KNO₃ probably does not have the same solubility characteristics as NaNO₃.
Additional Question

1. You have had some practice by now in planning and carrying out investigations. Imagine you are telling a younger student how to plan an investigation. Write one suggestion for how to do each step successfully:

- Asking a question: For example, make sure you ask a question that you can find an answer to.

- Formulating a testable hypothesis: For example, use what you already know about the science explanations to think about what might happen.

- Selecting equipment and technology: For example, if you have an opportunity to use probeware, use it, because this gives the most accurate results.

- Writing a procedure: For example, remember to include recording your data in your procedure so you do not forget to do it in the middle of the investigation.

- Carrying out your plan and recording data: For example, record all your data and observations, even if you are not sure if you need it all. It is easier to record everything than it is to go back and get more observations.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct investigations using:
    - Fair test – changing only one variable at a time makes comparisons valid
    - Independent variable – the one variable the investigator chooses to change
    - Dependent variables – what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
    - Temperature
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Bunsen burner
    - Thermometer
    - Balance
    - Graduated cylinder
    - Test tube
    - Other laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Graph

- Interpret Data
  - Identify and interpret patterns using:
    - Trends in data
    - Graphed data points

- Evaluate Evidence
  - Draw and support a conclusion by:
Using data to determine the cause-effect relationship observed in the investigation
- Reporting trends and patterns in the data
- Comparing results to hypothesis

- Communication in Science
  - Report results using:
    - Table/graph showing data

- Patterns and Systems
  - Patterns and Change
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    - Things that change may do so in steady, repetitive or irregular ways.
    - Many patterns in nature contain symmetry.
    - Mathematical patterns help to predict future events and describe change in systems.

- Scientific Investigation
  - Science investigation begins with a testable question.
  - When a scientific investigation is repeated, a similar result is expected.
  - Collecting and analyzing data is the best way to understand a changing pattern.
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.

- Scientific Endeavor
  - Characteristics of Science:
    - Scientific claims can be substantiated using data and observation.
Teacher Guide
Investigating the Effect of Pressure on the Solubility of Gases Solutions

In this investigation, students use soda to investigate the relationship between the partial pressure of gas above a liquid and the amount of gas a given volume of the liquid can hold. The lab is qualitative but some students may wish to conduct a quantitative approach to the problem. Additional equipment, such as an accurate top pan balance, will be required for a quantitative approach.

Safety Precautions
- Follow all lab safety guidelines, especially those associated with dissection.
- Follow proper disposal and cleaning procedures after the lab, including wiping down your dissection area with disinfectant wipes and washing your hands with soap and water.
- Wear proper safety attire including closed toe shoes, safety goggles, lab coats or aprons, and gloves.
- Tie back long hair.
- Do not eat or drink anything in the lab.

Objective
In this investigation students, investigate how the pressure of gases above a liquid determines the solubility of gases in the liquid.

Materials
Per pair:
- bottle of carbonated water
- lab apron, one per student
- paper towels
Procedure

Tell students not to open the bottle until they are ready to start the investigation. Students should read the bottle label. Explain to them they that they are going to make observations about what happen when the bottle cap is released. Place these guiding questions on the board:

- What do you predict will happen when you loosen the bottle cap?
- What will happen if you quickly release the bottle cap and then immediately seal it?
- What will happen if you do this a few times?
- What will happen if you leave the top off for an extended period?
- What is causing the pressure in the closed bottle?
- What is the relationship between the pressure of gas in the bottle and the gas dissolved in the liquid?

Explain to students that they should use the investigation sheet to record their ideas, data, and conclusions. They should use what they record to help them answer the conclusion and analysis questions.

Analysis and Conclusion Questions

1. What did you predict would happen when you loosened the lid of the bottle?
   Sample answer: Answers will vary but most students will probably mention the water will fizz.

2. What did you observe when you loosened the lid and quickly closed it again? Explain this observation.
   Sample answer: The water fizzed but stopped fizzing when the bottle was closed again. When the cap is released, a gas dissolved in the water is comes out of the water. This is because the gas pressure above the water decreases when the cap is released.
3. What happens each time you repeat this procedure a few times? Explain these observations.
Sample answer: The water fizzes but there are fewer bubbles each time. This is because the pressure of the dissolved gas above the water decreases each time more gas is released.

4. Explain what happens when the bottle top is left off for an extended period.
Sample answer: Eventually the water almost stops fizzing. There are some bubbles but nothing like those seen initially. This is because the pressure of the gas inside the bottle (above the solution) has equilibrated with atmospheric pressure.

5. From your observations what conclusions can you make regarding the relationship between the (partial) pressure in the bottle and the amount of gas dissolved in the water?
Sample answer: The higher the pressure in the bottle the more gas is dissolved in the water. When the pressure above the water is decreased the gas dissolved in the water comes out of solution. Therefore, the amount of gas held in solution is directly proportional to the pressure it exerts above the water.
Hands-On Activity
Modeling the Dissolution Process

In this activity, students model the dissolution of a solute in a solvent. They develop an understanding of the process of dissolution and the role of intermolecular forces of attraction in this process.

**Suggested Materials**
Per Group:
- paper models of water molecules (50)
- paper models of cations (5)
- paper models of anions (5)
- paper models of methanol (5)
- paper models of hexane (5)
- paper, markers, and scissors for making additional models

For Demonstration:
- water
- table salt
- methanol
- hexane
- beakers (3)
- tablespoon
- stirring rod

**Procedure**
Prepare the suggested number of paper models for each group using the templates shown. Copy templates onto heavy cardstock and cut them out using scissors. Given the complexity of some of the shapes, you may need to leave some white space around the borders. Prepare the models for students prior to class and sort them into sandwich bags so that students can easily see what they have to work with.

1. To introduce the activity, let students know that they will be using the molecular models to construct larger models of solutions. Provide time for students to look at the types of molecules they have to work with and to begin thinking about different solution models they can build.
2. Begin the activity by carrying out a demonstration of adding table salt into a beaker of water. Stir the salt in the water until it dissolves. Ask students to think about what is happening at the molecular level. Then ask each group to create a model to explain why the salt can no longer be seen in the water. After groups have finished, have each group describe their model and explain how it demonstrates the dissolution process. Then have a class discussion to allow students to discuss which model they think best demonstrates how salt becomes dissolved in water. Follow up by asking: *What intermolecular forces of attraction are important to the dissolution process in this case?*
Modeling the Dissolution Process

3. Next, carry out a second demonstration in which you add methanol into a beaker of water. Stir the solution with a stirring rod to show students that methanol dissolves. Then ask each group to create a model to explain this dissolution example. As before, allow time for groups to develop their model. When all groups have finished, have each group describe their model and explain how it demonstrates the dissolution process. Have a class discussion to allow students to discuss which model they think best demonstrates how methanol becomes dissolved in water. Follow up by asking: What intermolecular forces of attraction are important to the dissolution process in this case?

4. Next, carry out a third demonstration in which you add hexane into a beaker of water. Stir the mixture with a stirring rod to show students that no matter how rapidly you mix the two liquids, the hexane does not dissolve in water. Instead, hexane forms a separate layer on top of the water. Ask each group to work with their models to explain why dissolution did not occur in this example. As before, allow time for groups to work with their models and develop their explanation. Once all groups have finished, have each group describe how their models can be used to explain the lack of dissolution in this case. Follow up by asking: What can you conclude about intermolecular forces of attraction in this case?

5. Finally, if time permits, have students try using the models to test other molecules as solvents. For example, they can test the solubility of hexane in methanol or the solubility of salt in hexane. Allow students to create their own models of additional compounds that they would like to test. Follow up by having students make sketches of their models on paper accompanied by written explanations of how the models demonstrate intermolecular interactions that either allow dissolution to occur or prevent dissolution from occurring.
Template:

Analysis and Conclusions

1. Model the interactions between water and table salt as salt is mixed with water. Draw a sketch of your model. What intermolecular forces of attraction are important to the dissolution process in this case?
   Sample response: See table below.

2. Model the interactions between water and methanol as methanol is mixed with water. Draw a sketch of your model. What intermolecular forces of attraction are important to the dissolution process in this case?
   Sample response: See table below.

3. Model the interactions between water and hexane as hexane is mixed with water. Draw a sketch of your model. What can you conclude about intermolecular forces of attraction in this case?
   Sample response: See table below.
Sample student responses:

<table>
<thead>
<tr>
<th>Substances combined:</th>
<th>Model:</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salt added to water</td>
<td><img src="image1.png" alt="Model" /></td>
<td>Water can be described as a dipole, with a partially positive end between the two hydrogen atoms and a partially negative end directly opposite. The negative end of the water dipole is attracted to positive ions and the positive end of the water dipole is attracted to negative ions as shown in the model.</td>
</tr>
<tr>
<td>Methanol added to water</td>
<td><img src="image2.png" alt="Model" /></td>
<td>The O-H bonds in water and in methanol are polar, which means that they can form hydrogen bonds with one another as shown in the model. These interactions allow water molecules to surround methanol molecules, causing them to dissolve.</td>
</tr>
<tr>
<td>Hexane added to water</td>
<td><img src="image3.png" alt="Model" /></td>
<td>Water molecules form hydrogen bonds with itself, which are strong intermolecular forces of attraction. Water and hexane interact only through van der Waals interactions, which are very weak. Therefore, water preferentially interacts with itself and not with hexane, and the two form separate layers.</td>
</tr>
</tbody>
</table>
In this activity, students will demonstrate the following Inquiry Skills:

- **Design Investigations**
  - Make or use models that
    - simulate the real thing that cannot easily be studied or manipulated
    - have as many details as possible replicated from the real thing
    - allow the testing of a hypothesis with results that can be extrapolated to the real thing
    - are based on logic and evidence

- **Patterns and Systems**
  - **Patterns and Change:**
    - Patterns in nature may be simple repeating patterns or complex growing or changing patterns.
    - Many patterns in nature contain symmetry.
    - Symmetry may determine properties of many objects, such as molecules, crystals, organisms, and designed structures.
  - **Systems:**
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
Hands-On Lab
Reactions in Solution

Timing: one 90-minute class session

Objective(s):
Students will investigate a variety of reactions in solution and distinguish between acid-base reactions, precipitation reactions, and gas-forming reactions. You may also choose to have students investigate oxidation-reduction reactions, if this material has already been covered in class.

Safety Precautions:
Remind students to be careful with the chemicals used in this lab, since several of them are toxic and corrosive. In particular, HCl and NaOH are corrosive to skin and tissue. Have the MSDS sheets for each chemical available in the classroom. Any chemical spills should be reported to you, and you should clean them up yourself. Remind students to follow all general lab safety rules, wear closed-toe shoes, and not to eat or drink anything in the lab. Students should never leave the lab area unattended with chemicals sitting out. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should follow all instructions for disposal and cleaning of the chemicals and their containers. Students should not try to clean up any spills or glass by themselves.

Materials:
For teacher demonstration:
- test tube rack
- 1 small test tube
- small stirring rod or test tube stopper with parafilm
- 3 mL of an 0.1 M aqueous solution of MgSO₄
- 3 mL of an 0.1 M aqueous solution of Na₂SO₄
- dropper
- wash bottle containing distilled water
- paper towels
- safety goggles and lab apron

Per student group:
- test tube rack
- 4 to 8 small test tubes
- small stirring rod
- about 10 mL of each of the following chemicals, all in 0.1 M aqueous solutions: MgSO₄, Ba(NO₃)₂, Na₂SO₄, Na₂CO₃, HCl, NaOH
- (optional) solid copper and zinc
- MSDS sheets for all of the chemicals listed above
- dropper
- wash bottle containing distilled water
- paper towels
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
Teacher Preparation:

- Print copies of the MSDS sheets for the chemicals used in this investigation, and have them available to students.
- Print out the Student Investigation Sheets.
- Provide copies of the solubility rules for students to reference. (See the Check Your Understanding assignment in Acids, Bases, and Salts titled Solubility Rules.)
- Prepare aqueous solutions of each compound. Student groups will use about 15 mL of each solution. Solution concentrations can vary, but try to keep all solutions around the same concentration (e.g., 0.1 M solutions of everything).

Procedure

1. Write the reactants for an acid-base and a precipitation reaction on the board. For example:
   \[ \text{HCl}(aq) + \text{NaOH}(aq) \rightarrow ? \]
   \[ \text{BaCl}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow ? \]

2. Ask: **What are the products of this reaction? What type of reaction is it, and how do you know?**
   \[ \text{HCl}(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O}(aq) + \text{NaCl}(aq) \quad \text{(acid-base reaction)} \]
   \[ \text{BaCl}_2(aq) + \text{Na}_2\text{SO}_4(s) \rightarrow \text{BaSO}_4(s) + 2\text{NaCl}(aq) \quad \text{(precipitation reaction, BaSO}_4\text{ precipitates out)} \]

3. **(optional)** Write a simple oxidation-reduction reaction on the board. For example:
   \[ \text{Cu}(s) + 2\text{AgNO}_3(aq) \rightarrow 2\text{Ag}(s) + \text{Cu(NO}_3)_2(aq) \]
   If oxidation-reduction reactions have not yet been covered, explain that students will learn about these reactions later in the course. Explain that they are another kind of reaction that can occur in solution. The purpose of students doing them now is to be able to distinguish them from acid-base and precipitation reactions. Give a very simple explanation of an oxidation-reduction reaction, pointing out that the copper has gone from being a solid with no charge, to a positive ion, and that the silver has gone from being a positive ion to a solid with no charge. Show the ionic equation for the reaction:
   \[ \text{Cu}(s) + 2\text{Ag}^+(aq) + 2\text{NO}_3^-(aq) \rightarrow 2\text{Ag}(s) + \text{Cu}^{2+}(aq) + 2\text{NO}_3^-(aq) \]
   Explain that this type of change (from no charge to charged) is characteristic of an oxidation-reduction reaction. Compare this type of reaction with the ionic equation of a precipitation reaction between dissolved salts, in which each ion keeps its charge before and after the reaction. (The BaSO_4 is not in ions because it is not dissolved, but it is still an ionic compound composed of Ba^{2+} ions and SO_4^{2-} ions.)
   \[ \text{Ba}^{2+}(aq) + 2\text{Cl}^-(aq) + 2\text{Na}^+(aq) + \text{SO}_4^{2-}(aq) \rightarrow \text{BaSO}_4(s) + 2\text{Na}^+(aq) + \text{Cl}^-(aq) \]

4. Tell students that they will be performing many different reactions in this investigation. They will predict the product of each reaction, and then carry it out. They will observe each reaction and record any precipitates, color changes, formation of gas, etc.

5. Tell students you will mix MgSO_4 and Na_2CO_3. Ask students to predict the products. Have them refer to solubility rules to determine whether a precipitate will form.

6. Use a dropper to put about 2 mL of MgSO_4 solution in a small test tube. Add about 2 mL of Na_2CO_3 solution. Mix using a small stirring rod. Ask a student to come up and report his or her observations.
Point out the formation of the precipitate. If the precipitate is hard to see, add 1 mL more of each reactant to the tube. If necessary, stopper the test tube and shake to mix the reactants thoroughly.

7. As students watch, dispose of the solution in an appropriate waste container, and rinse out the test tube and dropper using distilled water. Replace the test tube in the test tube rack. Tell students that since everything is in an aqueous solution, the test tube and dropper do not need to be dry for each reaction, but they do need to be rinsed thoroughly with distilled water.

8. Hand out copies of the Student Investigation Sheets and let students get to work. Students will plan their own investigations based on the teacher demonstration and on the charts provided on the Student Investigation Sheets.

Sample Data Tables

<table>
<thead>
<tr>
<th>Acid-Base and Precipitation Reactions</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Na₂CO₃</td>
<td>Na₂SO₄</td>
<td>NaOH</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>MgSO₄ + Na₂CO₃ → MgCO₃ + Na₂SO₄</td>
<td>MgSO₄ + Na₂SO₄ → no reaction</td>
<td>MgSO₄ + NaOH → Mg(OH)₂ + Na₂SO₄</td>
</tr>
<tr>
<td></td>
<td>Formation of precipitate MgCO₃</td>
<td></td>
<td>Formation of precipitate Mg(OH)₂</td>
</tr>
<tr>
<td>Ba(NO₃)₂</td>
<td>Ba(NO₃)₂ + Na₂CO₃ → BaCO₃ + 2NaNO₃</td>
<td>Ba(NO₃)₂ + Na₂SO₄ → BaSO₄ + 2NaNO₃</td>
<td>Ba(NO₃)₂ + 2NaOH → Ba(OH)₂ + 2NaNO₃</td>
</tr>
<tr>
<td></td>
<td>Formation of precipitate BaCO₃</td>
<td>Formation of precipitate BaSO₄</td>
<td>Formation of precipitate Ba(OH)₂</td>
</tr>
<tr>
<td>HCl</td>
<td>2HCl + Na₂CO₃ → H₂O + 2NaCl + CO₂(g)</td>
<td>HCl + Na₂SO₄ → H₂SO₄ + NaCl</td>
<td>HCl + NaOH → H₂O + NaCl</td>
</tr>
<tr>
<td></td>
<td>Acid-base reaction, formation of a gas</td>
<td>No reaction because everything is soluble in water</td>
<td>Acid-base reaction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Oxidation-Reduction Reactions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HCl</td>
</tr>
<tr>
<td>Cu (solid)</td>
<td>Cu + HCl → CuCl₂ + H₂(g)</td>
</tr>
<tr>
<td>Zn (solid)</td>
<td>Zn + HCl → ZnCl₂ + H₂(g)</td>
</tr>
</tbody>
</table>
Analysis and Conclusions

1. For each type of reaction, write the balanced chemical equations for two examples that you observed in the investigation.

Acid-base reactions: 
\[ \text{HCl}(aq) + \text{NaOH}(aq) \rightarrow \text{H}_2\text{O} + \text{NaCl}(aq) \]
\[ 2\text{HCl}(aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow \text{H}_2\text{O} + 2\text{NaCl}(aq) + \text{CO}_2(g) \]

Precipitation reactions: 
\[ \text{Ba(NO}_3\text{)}_2(aq) + \text{Na}_2\text{CO}_3(aq) \rightarrow \text{BaCO}_3(s) + 2\text{NaNO}_3(aq) \]
\[ \text{Ba(NO}_3\text{)}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{NaNO}_3(aq) \]

(if carried out) Oxidation-reduction reactions: 
\[ \text{Cu}(s) + 2\text{HCl}(aq) \rightarrow \text{H}_2(g) + \text{Cu(Cl)}_2(aq) \]
\[ 2\text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{H}_2(g) + 2\text{ZnCl}(aq) \]

Additional Questions

1. Define each type of reaction:

Acid-base reactions: An acid-base reaction is a reaction that takes place between an acid and a base to produce water and a salt.

Precipitation reactions: A precipitation reaction is a reaction in which the reactants are dissolved in solution, but one or more of the products is insoluble and precipitates out of solution.

2. Differentiate between acid-base and precipitation reactions. How are they similar? How are they different?

Both acid-base and precipitation reactions are reactions that take place in aqueous solutions. They both involve ions. However, acid-base reactions involve acids and bases neutralizing each other to produce water and a salt. Precipitation reactions do not involve neutralization. Instead, ions are exchanged to produce new products.

3. If you studied oxidation-reduction reactions in the investigation, explain how they are similar to and different from acid-base and precipitation reactions.

Like acid-base and precipitation reactions, the oxidation-reduction reactions we studied happened in solution and involved ions. However, the oxidation-reduction reactions we studied involved solid metals also, which is not a part of the other two types of reactions. Also, in the oxidation-reduction reactions we studied, an element (Cu and Zn) changed from having no charge as a pure element to having a charge after the reaction. This doesn’t happen in the other kinds of reactions. In acid-base and precipitation reactions, the charge on the ion stays the same before and after the reaction.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table
    - Chart
    - Writing (journal, worksheet, electronic text)

- Interpret Data
  - Identify and interpret patterns using:
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Comparing results to hypothesis
    - Answering the testable question
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Peer presentation
    - Written report
    - Table/graph showing data
Hands-On Activity
Solutions on Ice

Objective:
Students will investigate whether the presence of salt affects the temperature of chilled water.

Estimated time to complete: 15 minutes

Materials:
For each pair of students:
- graduated cylinder (100 mL)
- ice cubes (8)
- marker
- plastic spoons (2)
- Styrofoam cups (8 oz) (2)
- thermometer
- table salt
- water

Procedure:
Use the marker to label the cups as follows: “water” and “salt solution.” Add 100 mL water to each cup. Place the thermometer in the cup labeled “water” and allow it to sit undisturbed for a few minutes. In the meantime, add 2 spoonfuls of salt to the cup labeled “salt solution” and stir to dissolve. Read the temperature of the water sample and record it in a data table like the one shown below. Take an initial temperature reading of the salt solution and record it also.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initial Temperature</th>
<th>Temperature After Ice Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>salt solution</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Place 4 ice cubes in each sample and stir with the spoons. Be sure that students do not use thermometers to stir and that they use separate spoons for stirring the two solutions to avoid cross-contaminating the samples. Continue stirring for a few minutes to allow temperatures to equilibrate. Then measure the temperature of the water sample and record the result in the data table. Measure the temperature of the salt solution and record the result.

Ask students to think about the following questions:
- What final temperature do you predict for the water + ice?
- What final temperature do you predict for the salt solution + ice?
- Were your predictions correct?
- What can account for the differences in the temperatures of the samples on ice?
- How do the results of your investigation explain why it is useful to sprinkle salt on an icy sidewalk in winter?

Sample data:

<table>
<thead>
<tr>
<th>Sample</th>
<th>Initial Temperature</th>
<th>Temperature After Ice Addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>water</td>
<td>20 °C</td>
<td>1 °C</td>
</tr>
<tr>
<td>salt solution</td>
<td>20 °C</td>
<td>-2 °C</td>
</tr>
</tbody>
</table>
Inquiry and Nature of Science Skills in this Activity:

- **Identify Questions**
  - Develop a question that:
    - Asks a question about a specific science concept or process

- **Design Investigations**
  - Design and conduct investigations using:
    - Control (control group) – used for comparison in which the independent variable is not changed

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Temperature
  - Choose appropriate tools to conduct an investigation:
    - Thermometer
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns using:
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in data
    - Formulating scientific explanations/arguments

- **Patterns and Systems**
  - Patterns and Change:
    - Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    - Some small changes can be detected by taking measurements.
    - Things that change may do so in steady, repetitive or irregular ways.

- **Scientific Investigation**
  - Scientific Investigation:
    - Scientific investigation results in things we know and things we don’t know.
    - Scientific investigation leads to more questions.
    - Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
- Collecting and analyzing data is the best way to understand a changing pattern.
- Comparisons of data are not accurate when some of the conditions are not kept the same.
Exploration Teacher Guide: Solutions

Overview

A solute dissolves in a solvent to form a solution, a homogeneous mixture, that has the matter phase of the solvent and is usually a liquid. In this Exploration, students compare the solubility of ammonium chloride (NH₄Cl) and potassium chlorate (KClO₃) in 100g of water. They observe that the solubility of salts increases as temperature rises.

Student Learning Objectives

- Determine the solubility of salts in water.
- Investigate the effect of temperature on solubility.
- Compare the solubility of different salts.

Student Worksheet

The student worksheet includes questions for students. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students select a salt as the solute and the temperature using the Select Solute and Select Temperature dropdown lists. They then use the Add buttons to add 5g or 10g of the selected salt. A maximum of 80g of salt may be added. Students use the Mix button to add the salt to water in the beaker. After mixing, a feedback box describes the solubility of the salt at the selected temperature. They may increase or decrease the temperature to observe how the solubility of the salt changes.

Students may use the Reset button to begin over.

In the Tracker tab, students track the type of solute and the quantity of solute added to the solvent. They use this information to conclude that solubility of the solute increases with an increase in temperature.

Answers to Questions in the Student Worksheet

1. What is a solution? Identify the different constituents of a solution.

   **Answer:** A solution is a homogenous substance formed by dissolving one substance in another. The different constituents of a solution are the solute and the solvent. The solute is dissolved in the solvent. The solute is usually present in smaller quantities than the solvent.
2. Distinguish between a saturated and an unsaturated solution.

   **Answer:** A solution in which no more solute can be dissolved is known as a saturated solution. An unsaturated solution is one in which more solute can be dissolved.

3. Define the term ‘solubility’ and list factors that affect the solubility of a salt.

   **Answer:** Solubility is a measure of a solute’s tendency to dissolve in a solvent at a specific temperature and pressure. Solubility depends on temperature, pressure, surface area of the solute, polarity of solute, and the properties of the solvent.

4. Describe the relationship between temperature and solubility.

   **Answer:** An increase in the temperature of a solvent leads to an increase in the solubility of a solute. This means that more solute can be dissolved in a solution if the temperature of the solution is increased.

5. Why is water known as the universal solvent?

   **Answer:** Water is known as the universal solvent because it dissolves more substances than any other liquid. It is a polar molecule and can dissolve a wide variety of solutes.

6. Why are water molecules attracted to both positive ions and negative ions?

   **Answer:** A water molecule is made up of two positively charged hydrogen atoms and a negatively charged oxygen atom. This makes water a polar molecule that can dissolve both positive ions and negative ions.

7. Comment on the phrase 'like dissolves like' with respect to solubility. Explain why scrubbing with soap helps remove a greasy stain from clothing.

   **Answer:** The phrase 'like dissolves like' means that a solute dissolves in a solvent that has a similar chemical structure. Soap is made up of fatty acids. It has a chemical structure similar to grease. It also has a polar and nonpolar side. The polar side reacts with water and the nonpolar side reacts with the grease. Thus, it helps remove a greasy stain from clothing.
8. A mass of 100 g of sodium nitrate (NaNO₃) dissolves completely in 100 g of water at 80°C.

   a. Is the solution saturated or unsaturated?

   b. What will happen to the solution as it is cooled?

Answer:

   a. As 100 g of sodium nitrate dissolves completely in 100 g of water at 80°C, the solution is unsaturated at that temperature.

   b. The solution will become saturated as it cools.
Overview

A solute dissolves in a solvent to form a solution, a homogeneous mixture, that has the matter phase of the solvent and is usually a liquid. In this Exploration, students compare the solubility of ammonium chloride (NH₄Cl) and potassium chlorate (KClO₃) in 100g of water. They observe that the solubility of salts increases as temperature rises.

Student Learning Objectives

- Determine the solubility of salts in water.
- Investigate the effect of temperature on solubility.
- Compare the solubility of different salts.

Student Worksheet

The student worksheet includes questions for students. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, students select a salt as the solute and the temperature using the Select Solute and Select Temperature dropdown lists. They then use the Add buttons to add 5g or 10g of the selected salt. A maximum of 80g of salt may be added. Students use the Mix button to add the salt to water in the beaker. After mixing, a feedback box describes the solubility of the salt at the selected temperature. They may increase or decrease the temperature to observe how the solubility of the salt changes.

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1. What is a solution? Identify the different constituents of a solution.

   Answer: A solution is a homogenous substance formed by dissolving one substance in another. The different constituents of a solution are the solute and the solvent. The solute is dissolved in the solvent. The solute is usually present in smaller quantities than the solvent.
2. Distinguish between a saturated and an unsaturated solution.

   **Answer:** A solution in which no more solute can be dissolved is known as a saturated solution. An unsaturated solution is one in which more solute can be dissolved.

3. Define the term ‘solubility’ and list factors that affect the solubility of a salt.

   **Answer:** Solubility is a measure of a solute’s tendency to dissolve in a solvent at a specific temperature and pressure. Solubility depends on temperature, pressure, surface area of the solute, polarity of solute, and the properties of the solvent.

4. Describe the relationship between temperature and solubility.

   **Answer:** An increase in the temperature of a solvent leads to an increase in the solubility of a solute. This means that more solute can be dissolved in a solution if the temperature of the solution is increased.

5. Why is water known as the universal solvent?

   **Answer:** Water is known as the universal solvent because it dissolves more substances than any other liquid. It is a polar molecule and can dissolve a wide variety of solutes.

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   **Answer:** A water molecule is made up of two positively charged hydrogen atoms and a negatively charged oxygen atom. This makes water a polar molecule that can dissolve both positive ions and negative ions.

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   **Answer:** The phrase ‘like dissolves like’ means that a solute dissolves in a solvent that has a similar chemical structure. Soap is made up of fatty acids. It has a chemical structure similar to grease. It also has a polar and nonpolar side. The polar side reacts with water and the nonpolar side reacts with the grease. Thus, it helps remove a greasy stain from clothing.
8. A mass of 100 g of sodium nitrate (NaNO₃) dissolves completely in 100 g of water at 80ºC.

   a. Is the solution saturated or unsaturated?

   b. What will happen to the solution as it is cooled?

**Answer:**

   a. As 100 g of sodium nitrate dissolves completely in 100 g of water at 80ºC, the solution is unsaturated at that temperature.

   b. The solution will become saturated as it cools.
Hands-On Lab
Super Solubility

Timing: one 90-minute class session

Objective(s):
Students will investigate how temperature, surface area, and stirring affect the rate of solution.

Safety Precautions:
Remind students to follow all general lab safety rules, wear closed-toe shoes, and not eat or drink anything in the lab. Students should never leave the lab area unattended with the hot plate turned on. Remind students to wear safety equipment including goggles, gloves, and lab aprons. Students should report any chemical spills or broken glass immediately and should not try to clean up any spills or glass by themselves.

Materials:
Per group:
- graduated beakers, 6–8
- stirring stick
- hot plate
- access to balance
- ice
- stopwatch or timer
- safety goggles, one pair per student
- lab apron, one per student
- one of the following:
  - sugar (cubed and granular)
  - salt (rock and granular)
Teacher Preparation:
- Gather materials in advance of students performing the lab.

Procedure (Parts 1, 2, and 3)

1. Assign each student group to one of two solutes: sugar or salt.
2. Distribute solutes to students.
   - Give the sugar groups cube and granular forms of sugar.
   - Give the salt groups rock and granular forms of salt.
3. Have students collect the necessary materials (or provide these on the student tables prior to the start of class).
4. Explain that each group will need to design experiments to test the effect of temperature, surface area, and stirring on the rate of solution.
5. As a class, discuss the importance of control variables in the experiments. Specifically, encourage students to use the granular forms for most experiments, but do not tell them that the larger forms take too long to dissolve.
6. Have students design and conduct their experiments. The final results should be measurements of how long it took each solute to dissolve to the point where clumps are no longer visible. For all three parts, students will record their results in tables of their own design on the Student Investigation Sheet. You may need to provide students with extra paper if they run out of room for their tables
   I. For temperature, students will measure dissolution rates using cold water, room-temperature water, and heated water.
   II. For surface area, students will measure dissolution rates for the larger and smaller solute forms.
   III. For stirring, students will measure dissolution rates for stirring and not stirring.
7. Have each group put their results on chart paper or the board.
8. Student groups should describe a general rule for each factor, using collision theory in their explanation.
9. To help students, you may want to ask them to discuss what is happening at the molecular level when solutions are heated or stirred.
Analysis and Conclusions

1. How does temperature affect the rate of solution? Use collision theory to explain this effect. Sample answer: Increasing the temperature increases the kinetic energy of the particles. As the particles move more quickly, they collide more frequently, increasing the rate at which they dissolve.

2. How does stirring affect the rate of solution? Use collision theory to explain this effect. Sample answer: Stirring increases the rate of solution because the agitation causes the particles to collide more often. This increases the rate at which the solute dissolves.

3. How does surface area affect the rate of solution? Use collision theory to explain this effect. Sample answer: As surface area increases, the rate of solution increases. This is because there is more area of the solute that can collide with other particles.

4. What is the best strategy for dissolving a solute quickly in a solvent? Explain. Sample answer: The best strategy is to use small particles, stir the solution, and increase the temperature. This will maximize the rate of collision of the particles.
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify Questions**
  - Recognize and develop testable questions that
    - specify a cause-effect relationship
    - require the changing of one variable at a time
    - can be answered with a science investigation or observational study
    - function exactly like or similarly to the real thing

- **Design Investigations**
  - Design and conduct investigations using
    - independent variable – the one variable the investigator chooses to change
    - dependent variables – what changes as a result of, or in response to, the change in the independent variable
  - Practice lab safety by
    - following lab safety procedures

- **Gather Data**
  - Use tools to accurately measure
    - time
  - Use senses to observe
    - seeing (color, shape, size, texture, motion)

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by
    - using data to determine the cause-effect relationship observed in the investigation
    - articulating a conclusion that is based on evidence and that answers a testable conclusion
    - drawing a conclusion that incorporates prior knowledge
Hands-On Lab
Thermodynamics of a Solution

Timing: one 90-minute class session

Objective(s):
In this lab, students will use calorimetry to measure the change in enthalpy as solid urea dissolves in water to form a 1 M urea solution. They will observe that the process is spontaneous and use this observation along with the relationship $\Delta G = \Delta H - T\Delta S$ to evaluate $\Delta S$ for the dissolution process.

Safety Precautions:
Students should be instructed not to use the thermometer for stirring. If any thermometer breaks or if a spill occurs, students should report this event immediately and not try to clean it up on their own. Long hair should be tied back, and students should wear safety goggles, lab apron, and closed-toed shoes during the lab.

Materials:
Per pair of students:
- coffee cups, disposable polystyrene (2)
- graduated cylinder, 50 mL
- spatula
- stirring rod
- thermometer (0°C –100°C)
- urea (10 g)
- water, deionized or distilled
- goggles
- lab apron

Per class:
- electronic balance
- NaOH (1–2 g) for demonstration

Teacher Preparation:
- Just before class, weigh the solid solute and measure the volume of water to be used to demonstrate the calorimetry procedure.
- Prepare a copy of the Student Investigation Sheet for each student.
Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to
the investigational methods being used in the Hands-On Lab, it is recommended that the Directed
Inquiry approach be used to provide scaffolding that will ensure student safety and support the success
of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory
techniques and methods to be used in the activity. A discussion of each step in the investigative
process will also be included. In some cases, students may then be asked to create a procedure based
on the one modeled for them. This may involve changing specific variables or adjusting the procedure
to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry
activity. During Guided Inquiry, students are allowed to conduct the investigations more independently.
They will be given opportunities to formulate their own questions, develop their own procedures, and/or
manipulate variables of their own choosing. It may be necessary to provide additional materials and
supplies for students using Guided Inquiry. It will also be important to set clear limits on students’
activities to ensure their safety and the relevance of their inquiry experience to the content you are
teaching.

Directed Inquiry
Demonstrate the use of a homemade calorimeter to find the enthalpy change ($\Delta H$) for a salt dissolving
in water. The following uses sodium hydroxide as an example. Be aware that sodium hydroxide is
causitic and can cause burns to the skin. Be sure to wear safety goggles and avoid contact with skin as
you handle the solid sodium hydroxide and the solution. Flush the solution down the sink with plenty of
water following the demonstration.

1. Insert one coffee cup into the other to make the calorimeter.
2. Measure 50.0 mL water in a graduated cylinder and add it to the calorimeter. Place the
   thermometer in the water and allow it to sit undisturbed for a few minutes to reach a stable
   reading.
3. Measure between 1 and 2 g sodium hydroxide (or other exothermic salt) in a weigh boat or on
   weighing paper. Record the exact mass of the solid.
4. Read the temperature of the water in the calorimeter and record in a data table like the sample
   shown.
5. Add the sodium hydroxide to the water in a quick motion. Then, immediately stir the mixture with
   the stirring rod.
6. Observe the temperature of the solution within the first few seconds of adding the solid. The
   temperature of this solution will increase above the original temperature of the water. Record
   the highest temperature observed.
7. Use the data to calculate the molar enthalpy change of sodium hydroxide dissolving in water
   where $m$ is the mass of solution (solute + water), $C$ is the specific heat of water, and $\Delta T$ is the
   change in temperature as the solid dissolved in water.
Note that degrees Celsius can be used to find the change in temperature since the change in kelvins is equivalent to the change in degrees Celsius.

The molar enthalpy change is found by dividing $\Delta H$ by the moles of sodium hydroxide used:

1. Review the equation $\Delta G = \Delta H - T\Delta S$. Ask students which values are known and which are unknown. ($\Delta H$ and $T$ are known; $\Delta G$ and $\Delta S$ are unknown.) Tell students that when they reach this point in their own investigation that you will provide them with the $\Delta G$ value. However, tell students that they must first explain the sign of $\Delta G$ (positive or negative) for their sample before you provide them with its actual value. Ask students how they will know the sign on $\Delta G$. (If the reaction is spontaneous, then the sign on $\Delta G$ will be negative. If the reaction is not spontaneous, then the sign on $\Delta G$ will be positive. We will have to decide whether the reaction is spontaneous or not.)

2. Finally, ask students how they will determine $\Delta S$. (Insert values for $\Delta G$, $\Delta H$, and $T$ into the equation $\Delta G = \Delta H - T\Delta S$ and solve for the one unknown, which is $\Delta S$.)
Sample data table:

<table>
<thead>
<tr>
<th>Trial</th>
<th>Mass of solute (g)</th>
<th>Volume of water (mL)</th>
<th>Temperature of water (°C)</th>
<th>Final temperature of solution (°C)</th>
<th>Calculated ΔH</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td>Average ΔH</td>
<td></td>
</tr>
</tbody>
</table>

**Guided Inquiry**

Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- Will you run only one trial?
- Why will it be helpful to run more than one trial?
- What will vary from trial to trial and what will stay constant?

Tell students that they will be doing an analysis of the thermodynamics of urea dissolving in water. They must find ΔH per mole of urea using calorimetry. Then you will provide the ΔG value for the process once students describe the correct sign they expect for ΔG. From there, students can calculate ΔS for the dissolution process.

Reference information: ΔH = +17.6 \times 10^3 \text{ J/mol}; ΔG = -5.77 \times 10^3 \text{ J/mol}; ΔS = +77.0 \text{ J/mol}

Note that dissolving a mass of 3 grams of urea in 50.0 mL water will result in approximately 1 M urea solution.

**Analysis and Conclusions:**
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Did urea dissolve in water spontaneously? How do you know? *Yes, urea dissolves in water spontaneously because no external energy had to be applied to cause it to dissolve.*

2. Was the dissolution of urea in water an endothermic or exothermic process? How do you know? *The dissolution process was endothermic because the temperature decreased as soon as we added urea to the water.*

3. Describe whether entropy increases or decreases as urea dissolves in water. How do you know? *Entropy increases because the sign on $\Delta S$ was positive when we finished all of our calculations.*

4. Complete the following table by indicating the correct sign for $\Delta S$ in each empty cell in the third column. Then indicate which of the four possibilities describes the urea dissolution process.

<table>
<thead>
<tr>
<th>$\Delta G = \Delta H - T\Delta S$</th>
<th>+</th>
<th>-</th>
<th>at all temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>+</td>
<td>at all temperatures</td>
</tr>
<tr>
<td>+</td>
<td>-</td>
<td>-</td>
<td>at high temperatures</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>at low temperatures</td>
</tr>
<tr>
<td>-</td>
<td>+</td>
<td>+</td>
<td>at high temperatures</td>
</tr>
<tr>
<td>+</td>
<td>+</td>
<td>+</td>
<td>at low temperatures</td>
</tr>
</tbody>
</table>
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Constant - identify variables that must remain unchanged
    - Multiple trials - repeated tests with the same variables to check for variability of results
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
    - Temperature
  - Choose appropriate tools to conduct an investigation:
    - Thermometer
    - Balance
    - Graduated cylinder
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Tables

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated
Patterns and Systems
  ○ Patterns and Change:
    ● Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    ● Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    ● Some small changes can be detected by taking measurements.
    ● Mathematical patterns help to predict future events and describe change in systems.

Scientific Investigation
  ○ Scientific Investigation:
    ● When a scientific investigation is repeated, a similar result is expected.
    ● Scientific investigations lead to the development of scientific explanations.
  ○ Scientific Data and Outcomes:
    ● Scientific claims are based on data and reliable scientific sources.
    ● Collecting and analyzing data is the best way to understand a changing pattern.
    ● Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ● Comparisons of data are not accurate when some of the conditions are not kept the same.

Scientific Endeavor
  ○ Characteristics of Science:
    ● Scientific claims can be substantiated using data and observation.
    ● Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Hands-On Activity
Two Liquids

Objective:
Students will observe four clear, colorless liquids using their senses of sight and taste. They will use their observations to conclude that a solution is composed of a solute dissolved in a solvent.

Estimated time to complete: 10 minutes

Materials:
For each class of 25 students:
- 50 disposable paper cups (2 or 3 oz)
- two identical clear plastic pitchers (1 L)
- water
- salt water (2 teaspoons per liter)

Procedure:
Place each liquid in a different pitcher. Both liquids should be clear and colorless. Arrange the pitchers at a central location. Instruct students to pour themselves a small sample of each liquid and return to their seats. Ask students to write observations of each liquid in their notebooks.

**Emphasize to students that they are never to taste anything in the chemistry classroom or lab without specific directions from the teacher to do so.** Explain that they are being allowed to taste this solution only because you mixed it yourself and know it is safe. Then ask students to taste each liquid and record pertinent observations in their notebooks.

Note: If time allows, you might want to provide salt solutions at two additional concentrations and have students compare their observations of these to the first two solutions. This can be tied into the discussion of concentration that comes later in the lesson.

Ask students to think about the following questions:
- How are the liquids similar?
- How are the liquids different?
- Based on your past experiences, can you identify each liquid?
- If you can identify either or both liquids, name each and describe each.
- How does this activity help you think about the composition of a solution?
Inquiry and Nature of Science Skills in this Activity:

- **Gather Data**
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Smelling (flavor, odor)
  - Use the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Formulating scientific explanations/arguments

- **Scientific Investigation**
  - Scientific Investigation:
    - Scientific investigation results in things we know and things we don't know.
    - Scientific investigation leads to more questions.
    - Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
    - Scientific investigations lead to the development of scientific explanations.
Hands-On Lab
Using Conductivity to Determine the Concentration of a Solution

Timing: one 90-minute class session

Objective(s):
Students will measure the conductivity of several known concentrations of aqueous NaCl solution, CaCl$_2$ solution, and/or AlCl$_3$ solution. They will use their data to draw graphs of conductivity versus concentration for each compound. Students will then extrapolate from their graphs to identify the concentration of a new solution of each compound.

Safety Precautions:
- Aqueous CaCl$_2$ and AlCl$_3$ may cause skin irritations, and may irritate or burn if they come in contact with the eyes. Both are harmful if ingested. Have an eye wash station available.
- Students should not eat or drink anything in lab.
- Students should wear closed-toed shoes, eye protection, gloves, and aprons.

Materials:
Per student group of 4 (if testing all three compounds) or 2 (if testing only one compound):
- 300 mL of 0.10 M solution for each compound: NaCl, CaCl$_2$, and AlCl$_3$ (Note: For a shorter lab, assign one compound to each student group and have groups share data.)
- wash bottle with distilled or deionized water
- 100 mL graduated cylinder and/or 20 mL pipette
- 250 mL beakers (anywhere from 12 per group to 1 per group depending on the procedure used and number of compounds being tested)
- wax pencils or another method to label beakers
- large water bath that can hold 4–6 250 mL beakers at once OR a small water bath to hold just one beaker
- stir bar and magnetic stirrer
- metal stand with clamp
- thermometer
- conductivity meter or probeware with conductivity electrodes
- graphing calculator or computer graphing program
Teacher Preparation:
1. Decide whether to have students work in groups of 4 to measure conductivity for all three compounds, or whether to assign one compound to each student pair, and have pairs share data. Each student will still create a graph for each compound, whether they use their own data or shared data.

2. Prepare the following solutions:
   - 0.10 M solution of NaCl (300 mL per student group)
   - 0.10 M solution of CaCl₂ (300 mL per student group)
   - 0.10 M solution of AlCl₃ (300 mL per student group)
   - various solutions with “unknown” concentrations: e.g., 0.03 M solution of NaCl, 0.05 M solution of CaCl₂, and 0.07 M solution of AlCl₃ (about 100 mL of each per group)

3. Prepare a copy of the Student Investigation Sheet for each student.

4. If you will be using the Directed Inquiry approach, prepare a copy of the Sample Procedure in this document for each student group.

5. Take time to become familiar with the conductivity meters or probeware being used, along with the graphing programs available. Read the instructions and be prepared to explain their use to the class.

Procedure:
This Hands-On Lab includes both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.
**Directed Inquiry**

1. Start the class by asking questions about conductivity and concentration in a solution:
   - Ionic solutions can conduct electricity. How do you think this is possible?
   - Would you expect a concentrated solution to be more or less conductive than a dilute solution? Why?
   - If you had solutions of NaCl, CaCl₂, and AlCl₃ all at the same concentration, which one would you expect to be most conductive? Which would you expect to be least conductive? Why?
   - You will be measuring the conductivity of solutions at several different concentrations. How might you use your data to determine the unknown concentration of a solution of the same compound?

2. Inform student groups that they will measure the conductivity of various concentrations of a solution. They will use their data to plot a graph of conductivity versus concentration. Later, they will be given a solution of the same compound with an unknown concentration. Students will use their graphs to determine the unknown concentration.

3. Tell students that solutions of three different compounds are being tested: NaCl, CaCl₂, and AlCl₃. Assign compounds to student groups, or inform groups that they will be testing all three compounds.

4. If students will be using probeware and graphing programs, instruct students how to set up and use the equipment. Provide a short demonstration. If students are using simple conductivity meters, demonstrate how to use the meters to obtain readings.

5. Hand out Student Investigation Sheets and copies of the Sample Procedure (on the next page) and let students start.
Sample Procedure for Directed Inquiry

1. Set up your equipment. Attach a clamp to the stand to hold the conductivity electrode. Place the magnetic stirrer below the electrode and adjust the height. Each solution will be stirred as the conductivity is measured. Make sure the electrode will not hit the stir bar.

2. You have been given a solution with concentration 0.10 M. You will dilute this solution to produce at least four solutions in total with known concentrations. Decide how you will do this. For example:
   - Combine 20 mL of 0.10 M solution with 100 mL distilled water $\rightarrow$ 0.02 M solution
   - Combine 40 mL of 0.10 M solution with 100 mL distilled water $\rightarrow$ 0.04 M solution
   - Combine 60 mL of 0.10 M solution with 100 mL distilled water $\rightarrow$ 0.06 M solution
   - Combine 80 mL of 0.10 M solution with 100 mL distilled water $\rightarrow$ 0.08 M solution
   - Use 100 mL of 0.10 M solution $\rightarrow$ 0.10 M solution

   OR: Place 100 mL of 0.10 M solution in a beaker and repeatedly add 20 mL of distilled water and stir to form each successive diluted solution. Remember to calculate the concentrations of the solutions this process would produce.

3. Prepare and label your solutions. You should measure conductivity for at least four solutions with different concentrations. (If you have more than one compound to test, work on one compound at a time to avoid confusing the solutions.)

4. Prepare the water bath with water at 25°C. Add hot or cold water to reach the desired temperature. Leave the thermometer in the bath so you can check it every once in a while and adjust the temperature of the bath as needed.

5. If your water bath is big enough to fit all the beakers with your solutions, place them in the bath and leave them there except while you measure conductivity. If your water bath just fits one beaker, place it on the magnetic stirrer under the conductivity electrode.

6. Prepare a table to record your observations.

7. Make predictions: Do you expect the conductivity of each solution to increase or decrease with concentration? Explain why. Which of the three compounds, NaCl, CaCl$_2$, or AlCl$_3$, do you expect to have the highest conductivity? Explain why.

8. Measure the conductivity of each solution as follows:
   - Put a clean, dry stir bar in the beaker containing the solution.
   - Place the beaker and solution on the magnetic stirrer. If you are using a small water bath, place the beaker in the bath.
   - Adjust the height of the conductivity electrode so that it is below the surface of the solution, but will not hit the stir bar.
   - Turn on the magnetic stirrer. If necessary, wait a few minutes until the solution is close to 25°C.
   - Measure the conductivity. This may take about a minute.
   - Record the conductivity and the concentration of the solution. If you are using a graphing program, input the data.

9. If you have more compounds to test, repeat steps 2 to 8 for each compound.
10. After you have measured each solution, prepare a graph of conductivity versus concentration for each compound. If you tested only one compound, share data with two other groups and use their data to draw up the other two graphs. Use a graphing calculator or graphing program if one is available.

11. Measure the conductivity of each solution with unknown concentration given to you by your teacher. Then use your graphs to determine the concentration of each solution.
Guided Inquiry

1. Students can develop their own plans for collecting data, based on their knowledge of the procedure modeled above and materials available. Ask the students some guiding questions to help them focus their inquiry:
   - How will you prepare solutions with different concentrations using the solution you are given?
   - How will you calculate the concentration of each diluted solution?
   - Do you expect conductivity to increase or decrease as you dilute the solution? Why?
   - Which of the three compounds do you expect to have the highest conductivity in solution, and why?
   - Which of the three compounds do you expect to have the lowest conductivity in solution, and why?
   - How will you graph conductivity versus concentration for each compound?
   - How will you use your graph to determine the unknown concentration?

2. Remind students that they should begin their activity by choosing a testable question.
   **Sample questions**: How can I prepare a graph of conductivity versus concentration, and how can I use this graph to identify unknown concentrations?

3. Remind students to handle solutions carefully. If necessary, discuss with the class how to dilute the solution to prepare other solutions with known concentrations. For example, students can:
   - Combine 20 mL of 0.10 M solution with 100 mL distilled water \(\rightarrow\) 0.02 M solution
   - Combine 40 mL of 0.10 M solution with 100 mL distilled water \(\rightarrow\) 0.04 M solution
   - Combine 60 mL of 0.10 M solution with 100 mL distilled water \(\rightarrow\) 0.06 M solution
   - Combine 80 mL of 0.10 M solution with 100 mL distilled water \(\rightarrow\) 0.08 M solution
   - Use 100 mL of 0.10 M solution \(\rightarrow\) 0.10 M solution

   OR, students can place 100 mL of 0.10 M solution in a beaker and repeatedly add 20 mL of distilled water and stir to form each successive diluted solution.

   Because students are graphing their results, it doesn’t matter if the solutions change concentration in even steps. However, it is essential that students are able to calculate the concentration of each diluted solution.

4. Have each student group design a procedure to answer their questions. Tell them to have their procedure approved before they begin their investigation. Remind students to define variables and create a hypothesis before they begin.

   **Dependent variable**: conductivity
   **Independent variable**: concentration

   **Sample hypotheses**: By preparing 5 solutions with varying concentrations and measuring their conductivities, I can prepare a graph of conductivity versus concentration that can be used to identify other unknown concentrations of the same compound.
Analysis and Conclusions:

1. How does conductivity change with concentration for a solution of an ionic compound? As the concentration decreases, the conductivity decreases also.

2. Write the dissociation equation for each compound: NaCl, CaCl₂, and AlCl₃.
   - NaCl → Na⁺ + Cl⁻
   - CaCl₂ → Ca²⁺ + 2Cl⁻
   - AlCl₃ → Al³⁺ + 3Cl⁻

3. Which compound would you expect to have the highest conductivity when dissolved in water to form a 1 M solution: NaCl, CaCl₂, or AlCl₃? Explain your answer. AlCl₃ has the highest conductivity because it produces the greatest number of ions (four ions in total). The more ions are present in the solution, the higher the conductivity, because there are more ions available to carry electrical charge.

4. Describe each graph. How did you use your graphs to identify unknown concentrations? For example, all three graphs were linear, but they had different slopes. To identify an unknown concentration, I measured the conductivity of the solution. On the graph, I started at that conductivity on the y-axis, went across until I reached the line, and went down to the x-axis to identify the concentration.

5. Evaluate your procedure. What worked well, and what would you do differently next time? 
   **Sample Response:** My procedure gave me a graph that accurately identified the unknown concentration, so it worked. I used just one beaker and diluted the solution by repeatedly adding 20 mL of distilled water. Although this procedure was simple and didn't use a lot of glassware, I couldn't repeat my measurements later. I had some trouble with my graph, and I would have liked to repeat one of the conductivity measurements. Next time I might make up all the solutions at the same time.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct field studies using:
    - Interventional Study - adjusts one or more elements and observes resulting changes over time
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged in
    - Multiple trials - repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design
• Gather Data
  o Use tools and the SI (metric) system to accurately measure:
    ▪ Volume
    ▪ Mass
  o Choose appropriate tools to conduct an investigation:
    ▪ Glassware (beakers, flasks, watch glass, etc.)
    ▪ Scale
    ▪ Graduated cylinder
    ▪ Other Laboratory equipment
  o Use senses to observe:
    ▪ Seeing (color, shape, size, texture, motion)
  o Use the appropriate format to record data:
    ▪ Table
    ▪ Graph
    ▪ Writing (journal, worksheet, electronic text)
• Interpret Data
  o Identify and interpret patterns using:
    ▪ Analysis of data collected during an investigation
• Evaluate Evidence
  o Draw and support a conclusion by:
    ▪ Answering the testable question
    ▪ Examining how investigations can be improved
    ▪ Formulating scientific explanations/arguments
    ▪ Showing the application of the scientific concept or process being investigated
• Communication in Science
  o Report results using:
    ▪ Written report
    ▪ Scientific explanations/arguments
    ▪ Table/graph showing data
• Patterns and Systems
  o Patterns and Change:
    ▪ Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    ▪ Some small changes can be detected by taking measurements.
Hands-On Activity
What’s in the Drinking Water?

Objective:
Students will observe two different samples of drinking water using their senses of sight and taste. They will use their observations to conclude that drinking water contains dissolved substances that affect the taste of the water.

Estimated time to complete: 10 minutes

Materials:
For each class of 25 students:
- 50 disposable paper cups (2 or 3 oz)
- two identical clear plastic pitchers (1 L)
- local tap water
- any brand of noncarbonated bottled drinking water

Procedure:
Place each sample of water in a different pitcher. Pitchers should be labeled “A” and “B” so that students cannot tell the source of either sample.

Inform students that each pitcher holds a sample of drinking water. Instruct students to pour themselves a small sample from each pitcher and return to their seats. Ask students to write observations of each sample in their notebooks.

Emphasize to students that they are never to taste anything in the chemistry classroom or lab without specific directions from the teacher to do so. Explain that they are being allowed to taste this solution only because you procured it yourself and know it is safe. Then ask students to taste each sample and record pertinent observations in their notebooks.

As they make their observations, ask students to think about the following questions:
- Is all drinking water the same?
- What could account for any differences you observe?
- What is the solvent in each sample you observed?
- What might the solutes be in each sample you observed?
Inquiry and Nature of Science Skills in this Activity:

- Gather Data
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
    - Smelling (flavor, odor)
  - Use the appropriate format to record data:
    - Writing (journal, worksheet, electronic text)

- Interpret Data
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Formulating scientific explanations/arguments

- Scientific Investigation
  - Scientific Investigation:
    - Scientific investigation results in things we know and things we don't know.
    - Scientific investigation leads to more questions.
    - Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
    - Scientific investigations lead to the development of scientific explanations.
Hands-On Lab
Acid-Base Titrations

Timing: one 90-minute class session

Objective(s):
Students will conduct an acid-base titration to determine the concentrations and pH of bases.

Safety Precautions:
This lab activity uses potentially dangerous chemicals, all of which must be handled and disposed of carefully. Strong acids and bases will irritate skin and damage other body tissues. Goggles, gloves, and aprons must be worn. Open-toed shoes should not be worn in the lab. Do not eat or drink anything in the lab. Spilled chemicals and broken glass should be reported immediately and cleaned up appropriately.

Materials:
Per pair or group:
- baking soda (4 g)
- balance
- buret (2)
- buret stand (1)
- Erlenmeyer flask, 250 mL (3)
- methyl orange
- phenolphthalein
- scoopula
- squirt bottle
- sodium hydroxide, NaOH, solution of unknown concentration (75 mL)
- 0.1 M sulfuric acid, H₂SO₄ (200 mL)
- water, deionized or distilled (250 mL)
- weigh boats

Teacher Preparation:
Clean, rinse (with distilled/deionized water), and dry all glassware thoroughly. Prepare stock solutions as necessary, depending on guided or directed approach. Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative...
process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Explain to students that they will be using 0.1 M sulfuric acid to determine the concentration of a sodium hydroxide solution. The procedure being used is called titration, and it involves the addition of small amounts of acid until the indicator shows that the basic solution has been neutralized. Show students the 50 mL of sodium hydroxide, a base. Ask them to predict the amount of acid it will take to neutralize the solution. Then have them complete the titration as described below.

1. Model for students the proper procedure for using a buret. Read the measurement at eye level, noting the bottom of the meniscus. Suggest that students use a piece of white paper with a thick black line drawn on it to improve the accuracy of their reading. Have them hold the paper behind the buret with the line along the bottom of the meniscus.
2. Rinse a buret with approximately 5 mL of 0.2 M sodium hydroxide to ensure all water or possible contamination is removed.
3. Using a buret, measure 25 mL of the sodium hydroxide solution into an Erlenmeyer flask.
4. Rinse a second buret with approximately 5 mL of 0.1 M sulfuric acid to ensure all water or possible contamination is removed.
5. Fill this buret with sulfuric acid to the 0.0 mL mark or as close as possible. Record the starting volume of acid in a data table.
6. Add two drops of phenolphthalein to the Erlenmeyer flask. Swirl gently. The solution should be pink.
7. Slowly add acid from the buret. Swirl the flask gently after each 2-3 mL is added, and watch for the pink color to disappear. Towards the end of the titration, add the acid drop by drop, swirling after each addition.
8. When the solution becomes colorless and remains so, record the ending volume of acid used during the titration.
9. Calculate the total volume of acid delivered from the buret to the flask.
10. Use this to calculate the concentration of the sodium hydroxide solution. If necessary, model for students how this is calculated.
11. This can be repeated as time permits. The concentration values determined for the sodium hydroxide solution are more accurate when averaged over multiple trials.
12. Clean up and dispose of all chemicals properly.

Sample Data Table:

<table>
<thead>
<tr>
<th>pH</th>
<th>[H+]</th>
<th>[OH⁻]</th>
<th>pOH</th>
<th>K_w</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Guided Inquiry
Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:
- What are your independent and dependent variables?
- Which indicator should be used and why?
- What is the equivalence point and what is the endpoint?
- What is the concentration of the unknown base?
- What is the concentration of the baking soda in water solution?

If students are able to complete a titration on their own, they can design their own procedure to determine the concentration of baking soda in solution. Instruct students to write down their procedures and have them approved before they begin work. A sample procedure might be as follows:
1. Rinse a buret with approximately 5 mL of 0.1 M sulfuric acid to ensure all water or possible contamination is removed.
2. Add 2.00 g of baking soda to a clean Erlenmeyer flask. Add 50 mL of water to the flask using a clean, graduated cylinder.
3. Fill the buret with sulfuric acid to the 0.0 mL mark or as close as possible. Record the starting volume of acid in a data table.
4. Add two drops of methyl orange to the Erlenmeyer flask. Swirl gently.
5. Slowly add the acid from the buret. Swirl the flask gently after each 2-3 mL and watch for a color change. Towards the end of the titration, add the acid drop by drop, swirling after each addition.
6. When the color of the solution in the flask changes, record the volume of acid used during the titration. (The solution should first appear yellow and then turn red.)
7. Calculate the total volume of acid delivered from the buret to the flask.
8. Calculate the concentration of the baking soda solution.
9. This can be repeated as time permits. The concentration values determined for the baking soda solution will be more accurate when averaged over multiple trials.
10. Clean up and dispose of chemicals properly.

Sample Data Table:

<table>
<thead>
<tr>
<th>pH</th>
<th>[H+]</th>
<th>[OH⁻]</th>
<th>pOH</th>
<th>Kw</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5</td>
<td>3.16 × 10⁻⁵</td>
<td>3.16 × 10⁻¹⁰</td>
<td>9.5</td>
<td>1.00 × 10⁻¹⁴</td>
</tr>
</tbody>
</table>
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What is the concentration of the sodium hydroxide solution? How did you determine this value? Answers may vary slightly depending on the students’ results.

An average amount of 42 mL of 0.1 M sulfuric acid (H$_2$SO$_4$) neutralized 25 mL of sodium hydroxide. Each mole of sulfuric acid will produce two moles of hydrogen ions (H$^+$). The concentration of H$^+$ is double that of the sulfuric acid, or 0.2 moles/liter, so [H$^+$]= 0.2 moles/liter.

In this case, 42 mL sulfuric acid was used. Since there are 0.2 moles per liter, the moles of H$^+$ ions can be calculated:

$$42 \text{ mL } H_2SO_4 \times \frac{1 \text{ L}}{1000 \text{ mL}} = 0.042 \text{ L } H_2SO_4$$

$$0.042 \text{ L } \times 0.2 \text{ moles } H^+ / \text{L} = 0.0084 \text{ moles } H^+$$

The moles of hydrogen ions formed by the acid equals the moles of hydroxide ions formed by the base. Therefore, there are $8.4 \times 10^{-3}$ moles OH$^-$. 

The amount if sodium hydroxide (NaOH) added was 25 mL:

$$25 \text{ mL } \times 1 \text{ L/1000 mL} = 0.025 \text{ L } NaOH$$

The concentration of NaOH equals the moles of OH$^-$ per liter:

$$0.0084 \text{ moles } OH^- \times 0.025 \text{ L} = 0.34 \text{ mol } OH^- / \text{L} = 0.34 \text{ M NaOH}$$

2. What were the equivalence points in your titrations? Answers will vary slightly depending on the actual concentrations of the solutions used. The titration of a strong acid (sulfuric acid) with a strong base (sodium hydroxide) will have an equivalence point around pH 7. The titration of a strong acid (sulfuric acid) with a weak base (baking soda) will have an equivalence point around pH 5.

3. What is the purpose of a titration? To determine the concentration of an unknown solution.

4. Draw the graph depicting each titration. What are the reactions and what are the products formed for each titration? Students should draw something that resembles a strong acid-strong base reaction and a strong acid-weak base reaction, as illustrated below, using the volumes they used in the activity.
Strong Acid-Strong Base Reaction

Caption: $\text{H}_2\text{SO}_4 + 2\text{NaOH} \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{O}$
When a strong acid is added to a strong base, the product has a pH of about 7.

Strong Acid-Weak Base Reaction

Caption: $\text{H}_2\text{SO}_4 + 2\text{NaHCO}_3 \rightarrow \text{Na}_2\text{SO}_4 + 2\text{H}_2\text{CO}_3$ (or $2\text{H}_2\text{O} + 2\text{CO}_2$)
When a strong acid is added to a weak base, the product has a pH around 6.

5. What are three possible sources of error in this titration activity? Answers may vary. Possible answers include: addition of too much titrant (acid) to the unknown base solution; calculation errors; solutions that were not initially prepared from stock at the appropriate concentrations, choosing the wrong indicator.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged in
    - Multiple trials - repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Balance
    - Pipette
    - Erlenmeyer flask
    - Graduated cylinder
    - Other Laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
- Table
- Graph
- Chart
- Writing (journal, worksheet, electronic text)

- Interpret Data
  - Identify and interpret patterns using:
    - Graphed data points
    - Tables and graphs
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Reporting trends and patterns in the data
    - Comparing results to hypothesis
    - Answering the testable question
    - Extrapolating results beyond the investigation
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Peer presentation
    - Written report
    - Scientific illustration with proper labeling
    - Scientific explanations/arguments
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
    - Identifying alternative explanations
    - Analyzing scientific explanations
    - Analyzing scientific arguments

- Scientific Investigation
  - Scientific Investigation:
    - Science investigation begins with a testable question.
    - When a scientific investigation is repeated, a similar result is expected.
    - Scientific investigation results in things we know and things we don't know.
    - Scientific investigations generally work the same way in different places.
    - Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    - Scientific investigation leads to more questions.
- Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
- What people expect to observe can affect how they perceive what they observe.
- Scientific investigations lead to the development of scientific explanations.
  - Scientific Data and Outcomes:
    - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    - Comparisons of data are not accurate when some of the conditions are not kept the same.
    - Accurate record keeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
    - It is important in science to keep honest, clear, and accurate records.
    - When similar investigations give different results, it often takes further studies to decide what is right.
    - Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.
- Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
    - Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory* leads to looking at old observations in a new way.
    - An important part of science is the critical review and analysis of any idea or conclusion.
- Engineering and Technology
  - Uses of Technology:
    - Not every problem has a technological solution.
Exploration Teacher Guide: Acids, Bases, and Salts

Overview

In this Exploration, students investigate how pH changes during titration and determine the unknown concentration of the sample solution.

Student Learning Objectives

- Investigate the four possible titration combinations with a strong acid, strong base, weak acid, and weak base. Learn which indicator is used in each titration.
- Identify the correct products that form after the neutralization process for each selected acid-base pair.
- Examine the change in the pH as the titrant is added and also the change in color of the pH indicator at equivalence point for different combinations of acid-base titrations.
- Determine the concentration of the beaker solution.
- Investigate how the shape of a pH curve changes when an acid is used as a titrant and when a base is used as a titrant.

Student Worksheet

The student worksheet includes questions for students. Students may review questions before going through the Exploration and can respond during or after they complete the Exploration.

Using this Exploration

In this Exploration, students learn about the titration process. The students select two options in the Apparatus tab to (1) understand the experimental setup and (2) to learn about pH sensor and drop counter.

In the Explore tab, students can select the titrant using options in the Burette Solution dropdown menu and the titer using options in the Beaker Solution dropdown menu. The options available in the Burette Solution dropdown menu are 0.5N sodium hydroxide and 0.5N sulfuric acid. The options available in the Beaker Solution dropdown menu are as follows:

Options for 0.5N sodium hydroxide

- Hydrochloric Acid
- Acetic Acid
- Oxalic Acid

Options for 0.5 N sulfuric acid

- Ammonium hydroxide
- Calcium hydroxide.

When the student selects the titer and titrant, the Indicator field displays a suitable indicator for that acid-base combination. A box presents the components of the chemical equation as the
titer and titrant are selected. Students must also select the correct product from the *Product* dropdown menu. The options available in the *Product* dropdown are:

- Sodium chloride + water
- Ammonium sulfate + water
- Sodium oxalate + water
- Sodium acetate + water
- Calcium sulfate + water

After the correct product is selected, the student uses the *Check* button to validate the reaction. The titration process begins after the correct reaction is identified.

The student uses the burette knob (highlighted button) to add the titrant to the titer. Each time the burette knob is clicked, the graph of pH versus titrant volume is updated with the data, allowing changes to be seen. As the beaker solution reaches the equivalence point, the window displays feedback. Students are guided to add a few more drops to complete the titration. After the titration is complete, students use the *Proceed* button to examine the graph of pH versus titrant volume and calculate and identify the normality of the titer.

Students can use the *Reset* button to begin over.

In the *Tracker* tab, students can review the various acid and base combinations they have successfully titrated. The student can note the selected burette (titrant) and beaker (titer) solutions, the products formed after neutralization, the unknown concentration of beaker solution (titer), pH at the equivalence point, and the volume of burette solution (titrant) used in the titration process.

**Answers to Questions in the Student Worksheet**

1. **Analyze and explain why sodium hydroxide is a strong base and ammonia is a weak base.**

   **Answer:** Sodium hydroxide on dissolution in water ionizes completely and produces sodium ions and hydroxide ions. Hence, sodium hydroxide is a strong base. Ammonia on dissolution in water ionizes feebly and produces ammonium ion and hydroxide ions. This reaction is a reversible reaction. Ions combine again to form ammonia and water molecules. This makes ammonia is a weak base.

2. **Differentiate monoprotic acids from diprotic acids using an example of each.**

   **Answer:** Monoprotic acids give one hydrogen ion in an aqueous solution. For example, hydrochloric acid (HCl)

   \[ \text{HCl} \rightarrow \text{H}^+ + \text{Cl}^- \]

   Diprotic acids give two hydrogen ions on dissolution in water. For example, oxalic acid (H$_2$C$_2$O$_4$)

   \[ \text{H}_2\text{C}_2\text{O}_4 \rightarrow \text{HC}_2\text{O}_4^- + \text{H}^+ \]

   \[ \text{HC}_2\text{O}_4^- \rightarrow \text{C}_2\text{O}_4^- + \text{H}^+ \]
The above reaction shows that oxalic acid gives two hydrogen ions in two steps. Hence, it is a dibasic acid.

3. Write the overall, ionic, and net ionic equations for the following reactions:
   a. Sodium hydroxide (NaOH) and oxalic acid (H₂C₂O₄)
   b. Hydrochloric acid (HCl) and ammonia (NH₃)

   **Answer:**
   a. Sodium hydroxide (NaOH) and oxalic acid (H₂C₂O₄)
      \[ 2\text{NaOH} + \text{H}_2\text{C}_2\text{O}_4 \rightarrow \text{Na}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O} \]
      \[ \text{Na}^+ + \text{OH}^- + 2\text{COO}^- + 2\text{H}^+ \rightarrow 2\text{H}_2\text{O} + 2\text{COO}^- + 2\text{Na}^+ \]
      \[ \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} (l) \]
   b. Hydrochloric acid (HCl) and ammonia (NH₃)
      \[ \text{HCl} + \text{NH}_3 \rightarrow \text{NH}_4\text{Cl} \]
      \[ \text{H}^+ + \text{Cl}^- + \text{NH}_3 \rightarrow \text{NH}_4^+ (aq) + \text{Cl}^- \]
      \[ \text{H}^+ + \text{NH}_3 \rightarrow \text{NH}_4^+ \]

4. Explain the role of a pH indicator in titration. Also, identify which indicator can be used in the titration of hydrochloric acid (HCl) with potassium hydroxide (KOH).

   **Answer:** The pH indicators are chemical dyes whose colors are affected by acidic and basic solutions. The indicator bromothymol blue can be used in the titration of hydrochloric acid (HCl) with potassium hydroxide (KOH).

5. From the following equivalence points, identify whether the titration involves a strong acid-weak base, a weak acid-strong base, or a strong acid-strong base. Also identify the color at the equivalence point.
   a. pH = 7.0
   b. pH = 8.8
   c. pH = 5.2

   **Answer:**
   a. The equivalence point, pH=7.0 indicates that the titration involves a strong acid-strong base. The indicator bromothymol blue can be used in this titration and its color at the equivalence point will be green.
   b. The equivalence point, pH=8.8 indicates that the titration involves a weak acid-strong base. The indicator phenolphthalein can be used in this titration and its color at the equivalence point will be pink.
   c. The equivalence point, pH = 5.2 indicates that the titration involves a strong acid-weak base. The indicator methyl red can be used in this titration and its color at the equivalence point will be red.
6. Calculate the normality of an oxalic acid (H₂C₂O₄) solution if 25.0 mL of this solution requires 35.0 mL of 0.198 N NaOH for complete neutralization.

Answer: The normality of this oxalic acid solution is 0.138 M.

7. Calculate the volume of 0.50 N H₂SO₄ required to be mixed with 35.0 mL of 0.60M Ca(OH)₂ to have a resulting solution with a pH of 7.0.

Answer: The volume of sulfuric acid required in this titration is 42 mL.

8. Write an overall reaction for the acid-base reaction that would be required to produce each of the following salts:
   a. KCl
   b. CaSO₄

Answer: The overall reactions for the acid-base reaction that would be required to produce each of the following salts are:
   a. KOH + HCl → KCl + H₂O
   b. Ca(OH)₂ + H₂SO₄ → CaSO₄ + 2H₂O

9. Identify which graph represents the titration between a strong base and a strong acid.

Figure 1: pH versus Volume

Answer: The curve in graph (a) represents a titration for a strong acid and a strong base.
10. Determine the pH of 0.1 M weak acid if its pKa = 7, where Ka is the dissociation constant of a weak acid.

**Answer:** The hydrogen ion concentration can be calculated as:

$$[H^+] = (\text{Ka} \cdot C)^{1/2} \quad (1)$$

Where, 
- Ka = dissociation constant of acid
- C = Concentration of acid

Ka = 10^{-7}
C = 0.1

Putting the above values in equation 1:

$$[H^+] = (0.1 \times 10^{-7})^{1/2} = 10^{-4}$$

pH = -log_{10}[H^+]

pH = -log_{10}(10^{-4})

pH = 4

Hence, the pH of this weak acid is 4.
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2. Differentiate monoprotic acids from diprotic acids using an example of each.

   **Answer:** Monoprotic acids give one hydrogen ion in an aqueous solution. For example, hydrochloric acid (HCl)
   
   \[ \text{HCl} \rightarrow \text{H}^+ + \text{Cl}^- \]

   Diprotic acids give two hydrogen ions on dissolution in water. For example, oxalic acid (H$_2$C$_2$O$_4$)
   
   \[ \text{H}_2\text{C}_2\text{O}_4 \rightarrow \text{H}^+ + \text{HC}_2\text{O}_4^- \]
   \[ \text{HC}_2\text{O}_4^- \rightarrow \text{C}_2\text{O}_4^- + \text{H}^+ \]
The above reaction shows that oxalic acid gives two hydrogen ions in two steps. Hence, it is a dibasic acid.

3. Write the overall, ionic, and net ionic equations for the following reactions:
   a. Sodium hydroxide (NaOH) and oxalic acid (H₂C₂O₄)
   b. Hydrochloric acid (HCl) and ammonia (NH₃)

   **Answer:**
   a. Sodium hydroxide (NaOH) and oxalic acid (H₂C₂O₄)
   \[
   2\text{NaOH} + \text{H}_2\text{C}_2\text{O}_4 \rightarrow \text{Na}_2\text{C}_2\text{O}_4 + 2\text{H}_2\text{O} \\
   \text{Na}^+ + \text{OH}^- + 2\text{COO}^- + 2\text{H}^+ \rightarrow 2\text{H}_2\text{O} + 2\text{COO}^- + 2\text{Na}^+ \\
   \text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O} (l)
   \]
   b. Hydrochloric acid (HCl) and ammonia (NH₃)
   \[
   \text{HCl} + \text{NH}_3 \rightarrow \text{NH}_4\text{Cl} \\
   \text{H}^+ + \text{Cl}^- + \text{NH}_3 \rightarrow \text{NH}_4^+ (aq) + \text{Cl}^- \\
   \text{H}^+ + \text{NH}_3 \rightarrow \text{NH}_4^+
   \]

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**Answer:** The normality of this oxalic acid solution is 0.138 M.

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**Answer:** The volume of sulfuric acid required in this titration is 42 mL.

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   a. KCl
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**Answer:** The overall reactions for the acid-base reaction that would be required to produce each of the following salts are:
   a. KOH + HCl → KCl + H₂O
   b. Ca(OH)₂ + H₂SO₄ → CaSO₄ + 2H₂O

9. Identify which graph represents the titration between a strong base and a strong acid.

**Figure 1: pH versus Volume**

![Graph](image)

**Answer:** The curve in graph (a) represents a titration for a strong acid and a strong base.
10. Determine the pH of 0.1 M weak acid if its pKa = 7, where Ka is the dissociation constant of a weak acid.

**Answer:** The hydrogen ion concentration can be calculated as:

\[ [H^+] = (Ka \times C)^{1/2} \]  

Where, 
- \( Ka \) = dissociation constant of acid
- \( C \) = Concentration of acid

\( Ka = 10^{-7} \)
\( C = 0.1 \)

Putting the above values in equation 1:

\[ [H^+] = (0.1 \times 10^{-7})^{1/2} = 10^{-4} \]

\[ pH = -\log_{10}[H^+] \]
\[ pH = -\log_{10}(10^{-4}) \]
\[ pH = 4 \]

Hence, the pH of this weak acid is 4.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.
- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Hands-On Activity
Identifying Acids and Bases

Objective:
Use an indicator to test predictions regarding whether common substances are acids or bases.

Estimated time to complete: 15 minutes

Materials:
For each small group:
- samples of every substances
- litmus or pH testing strips

Procedure:
Create a two-column chart. As a class, brainstorm a list of students’ perceptions about whether common substances are acids or bases.

Distribute to each small group samples of common acidic and basic substances such as baking soda, citrus, apples, soap, vinegar, dairy, distilled water, etc., that you have collected before class. Ask students to predict whether each substance they have been given will be acidic, basic, or neutral. Have them explain their predictions.

Distribute litmus or pH paper to the groups, and direct them to test the pH of each substance and record pH values in a graphic organizer or table. After testing is complete, ask students if their predictions were correct, and if not, why their results might have been different than anticipated.
Inquiry and Nature of Science Skills in this Activity:

- Identify Questions
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- Design Investigations
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Choose appropriate tools to conduct an investigation:
    - Other Laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
Hands-On Lab
Percent Dissociation of Acids and Bases

Timing: 45 minutes

Objective(s):
Students will investigate the degrees of dissociation of various acids and bases using conductivity and pH papers.

Safety Precautions:
- NaOH, HCl, and CH₃COOH can cause blindness and/or burns if splashed in eyes or on skin. Provide a working eyewash and emergency shower.
- Students must wear safety equipment including goggles, gloves, and lab aprons.
- Any spills should be treated as though they are acid or base spills and should be handled by the teacher.
- Remind students to be careful with the pH electrodes, and not to let them dry out.
- Remind students to follow all general lab safety rules, wear closed-toe shoes, tie back hair, and not to eat or drink anything in the lab.
- Students should never leave the lab area unattended with chemicals sitting out.
- Students should follow all instructions for disposal and cleaning of the chemicals and their containers.
- Students should report any broken glass immediately and should not try to clean up any glass by themselves.

Materials:
Per group of 4:
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
- metal stand with clamp for conductivity electrode
- stir bar and magnetic stirrer
- beakers, 250 mL, 8, dry and clean
- test tubes, 8
- beaker, 400 mL, for waste
- droppers
- material safety data sheets (MSDS) for HCl, NaOH, CH₃COOH, NaHCO₃
- pH paper
- conductivity meter or probeware with conductivity probes
- pH meter or probeware with pH probes (optional)
- instructions for the use of the conductivity electrodes
- wash bottle containing distilled water
- 0.01 M and 0.1 M solutions of the following acids and bases: HCl, NaOH, CH₃COOH, NaHCO₃
- paper towels
Teacher Preparation:

- Gather all materials in advance and set out the glassware and stands.
- Make copies of the MSDS sheets for the acids and bases students will be using in the lab. Make these available to students during the lab.
- Prepare the solutions of acids and bases in advance. Each student group will require about 100 mL of each. Ensure that all solutions are at room temperature.
- Set up the conductivity meters, pH meters (if used), and/or probeware and familiarize yourself with how they are used. Be prepared to explain their use to the class.
- Calibrate the conductivity meters and pH meters (if used) or probeware using standard solutions or be prepared to instruct students to calibrate them.

Part 1: Using pH to Assess Degree of Dissociation

Procedure

1. Students will work in groups of 4. Have students set up their stands, clamps, glassware, and other equipment.
2. Give students a few minutes to read through the student sheets. Provide copies of the MSDS sheets for students as well.
3. Encourage students to draw up tables in their notebooks in which to record their data.
4. Ask: What does the degree of dissociation tell you about the properties of an acid or base? Answer: The more an acid dissociates, the more ions it produces in solution, and the stronger it is. The same applies to a base.
5. Tell students that they will be testing two concentrations of each solution, a 0.01 M concentration and a 0.1 M concentration. Ask: How would you expect the pH of a solution to change as concentration increases or decreases? Explain why. Answer: A more dilute solution of acid will have a higher pH than a greater concentration of the same acid, because there will be fewer hydrogen ions present in the solution.
6. Instruct students to place about 1 mL of each solution in a test tube and use pH paper to determine its pH as accurately as possible. Students will record all data.
7. (optional) Have students place about 100 mL of each solution in a beaker and use the pH meter or probeware to calculate the pH of each solution. Students will record all data.
Part 2: Using Conductivity to Assess Degree of Dissociation

Procedure

8. Ask: **Why would a solution containing ions conduct electricity?** Answer: Because they are charged particles, ions are able to carry electrical charge from one place to another.

9. Ask: **How might conductivity relate to the degree of dissociation of an acid or base?** Answer: The more of an acid or base dissociates, the more ions will be produced, and the more conductive the solution will be.

10. Instruct students in the use of the conductivity meters or probeware being used. The meter may come with a temperature compensation feature, or students may need to input the temperature.

11. Have students clamp the conductivity probe to the stand and move the stand over the magnetic stirrer. For each solution in turn, students will clean and dry the stir bar, place it in a beaker containing about 100 mL of the solution, and position the beaker under the probe so that the probe is submerged in the solution but not in the way of the stir bar. They will wait for about a minute until the conductivity measurement has stabilized, and then record the measurement.

Part 3: Clean-Up

Procedure

12. Remind students to turn off the meter or probeware after they have measured the conductivity of each solution. Have them rinse the probe with distilled water and put the cap back on.

13. Remind students NOT to mix their used acids and bases together. Collect student acids and bases and neutralize them yourself. Dispose of the neutralized solutions in the appropriate waste containers.

Part 4: Calculations and Conclusions

Procedure

1. Students will use their observations from the investigation to assess the relative degrees of dissociation for each solution, depending on concentration.

2. Students will use their pH values to calculate the % dissociation for each pair of solutions using these equations:

\[
pH = - \log [H^+] \\
pOH = - \log [OH^-] \\
pH + pOH = 14
\]

and

\[
\text{percent dissociation of an acid} = \frac{[H^+]}{\text{initial concentration of acid}} \times 100 \\
\text{percent dissociation of an base} = \frac{[OH^-]}{\text{initial concentration of base}} \times 100
\]
3. (optional) You may want to have more advanced student groups use their pH data to calculate the dissociation constant for the weak acid (CH₃COOH) and the weak base (NaHCO₃).

The dissociation constant of CH₃COOH is $1.85 \times 10^{-5}$. The dissociation constant for NaHCO₃ is $2.4 \times 10^{-8}$.

4. (optional) It is possible to use the conductivity of various concentrations of an acid or base to calculate the dissociation constant. Advanced students may wish to research the process used and, if possible, use their conductivity data to calculate the dissociation constants and compare their answers to those calculated using pH.
Analysis and Conclusions

1. (a) Calculate the percent dissociation (% dissociation) for each solution of acid and base.

<table>
<thead>
<tr>
<th>Acid or Base</th>
<th>% dissociation of 0.1 M solution</th>
<th>% dissociation of 0.01 M solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>CH₃COOH</td>
<td>e.g., 1.25%</td>
<td>e.g., 3.98%</td>
</tr>
<tr>
<td>NaOH</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>NaHCO₃</td>
<td>e.g., 0.002%</td>
<td>e.g., 0.04%</td>
</tr>
</tbody>
</table>

(b) How does concentration affect the percent dissociation? Explain your answer.

For the strong acid and base, dissociation was not affected by concentration. For the weak acid and base, the percent dissociation increased the more dilute the solution was. Maybe this is because there is more room in a dilute solution for the ions to spread out.

2. Which compound is the weaker acid, HCl or CH₃COOH? Explain your answer.

CH₃COOH is the weaker acid, because its percent dissociation is less. HCl dissociated completely (100%) but CH₃COOH did not.

3. Which compound is the weaker base, NaOH or NaHCO₃? Explain your answer.

NaHCO₃ is the weaker base, because its percent dissociation is less. NaOH dissociated completely (100%) but NaHCO₃ did not.

4. How did concentration affect the pH of each acid? of each base? Explain why.

As the concentration of each acid decreased, the pH increased, because there were fewer hydrogen ions present. As the concentration of each base decreased, the pH decreased because there were more hydrogen ions present (and fewer hydroxide ions).

5. How did concentration affect the conductivity of each acid? of each base? Explain why.

As the concentration of each acid decreased, the conductivity of the solution decreased because there were fewer ions present. The same was true for the bases.

6. (a) Compare the degree of dissociation of a strong acid with that of a weak acid. Give an example of each.

A strong acid, such as HCl, dissociates completely in water. A weak acid, such as CH₃COOH, dissociates only partially in water. Some of the CH₃COOH remains undissociated.

(b) Compare the degree of dissociation of a strong base with that of a weak base. Give an example of each.

A strong base, such as NaOH, dissociates completely in water. A weak base, such as NaHCO₃, dissociates only partially in water. Some of the NaHCO₃ remains undissociated.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- **Design Investigations**
  - Design and conduct investigations using:
    - Fair test-changing only one variable at a time makes comparisons valid
    - Independent variable-the one variable the investigator chooses to change
    - Dependent variables-what changes as a result of, or in response to, the change in the independent variable
    - Constant-identify variables that must remain unchanged in
    - Multiple trials-repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Balance
    - Pipette
    - Erlenmeyer flask
    - Graduated cylinder
    - Other Laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
Use the appropriate format to record data:
  - Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
  - What people expect to observe can affect how they perceive what they observe.
  - Scientific investigations lead to the development of scientific explanations.

Scientific Data and Outcomes:
  - Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
  - Comparisons of data are not accurate when some of the conditions are not kept the same.
  - Accurate recordkeeping, openness, and replication are essential for maintaining an investigator's credibility with other scientists and society.
  - It is important in science to keep honest, clear, and accurate records.
  - When similar investigations give different results, it often takes further studies to decide what is right.
  - Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

Scientific Endeavor
  - Characteristics of Science:
    - Science is based on factual knowledge.
    - Scientists are curious about wanting to know how things work.
    - Scientific claims can be substantiated using data and observation.
    - Scientific theories are based on accumulated evidence.
    - Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way.
    - An important part of science is the critical review and analysis of any idea or conclusion.

Engineering and Technology
  - Uses of Technology:
    - Not every problem has a technological solution.
Hands-On Lab
Planning Your Own Acid-Base Titration Using Probeware

Timing: one 90-minute class session

Objective(s):
Students will perform an acid-base titration using a pH meter or probe, along with a graphing calculator or graphing computer program.

Safety Precautions:
- NaOH, HCl, and other acids and bases can cause blindness and/or burns if splashed in eyes or on skin. Provide a working eyewash and emergency shower.
- Students must wear safety equipment including goggles, gloves, and lab aprons.
- Any spills should be treated as though they are acid or base spills and should be handled by the teacher.
- Remind students to be careful with the pH electrodes, and not to let them dry out.
- Remind students to follow all general lab safety rules, wear closed-toe shoes, tie back hair, and not to eat or drink anything in the lab.
- Students should never leave the lab area unattended with chemicals sitting out.
- Students should follow all instructions for disposal and cleaning of the chemicals and their containers.
- Students should report any broken glass immediately and should not try to clean up any glass by themselves.

Materials:
Per pair:
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
- metal stands with clamps, 2 (one for the buret and one (if needed) for the pH electrode)
- buret, 50 mL, dry and clean
- beakers, 250 mL, 2
- beaker, 400 mL
- pipette or graduated cylinder, 100 mL
- watch glass
- scoop
- stirring rod
- funnel
- electronic balance
- stir bar and magnetic stirrer
- material safety data sheets (MSDS) for HCl and NaOH
- pH meter or probeware, attached to a graphing calculator or program
- instructions for the use of the pH meter or probeware
- wash bottle containing distilled water
- distilled water
- HCl (0.1 M)
- NaOH (0.1 M)
- paper towels
- access to a variety of common household acids and bases: baking soda, vinegar, lemon juice, antacid medication, or apple juice
Teacher Preparation:

- Gather all materials in advance. Collect a variety of harmless household acids and bases that are suitable for titration, such as those given in the materials list. **Warning: Do not allow students to titrate bleach, oven cleaners, drain cleaners, or other dangerous household chemicals. (Read the containers for warnings—bleach and some other household bases can emit toxic chlorine gas when reacted with acids.)**

- Prepare the 0.10 M solutions of HCl and NaOH in advance. Each student pair will need about 200 mL of 0.10 M HCl or NaOH. Other concentrations of these solutions can be used as long as students are given the correct known concentration.

- Set up the pH meters or probes and the graphing calculators or graphing programs. Calibrate the pH meters as directed by the instructional material provided with the equipment. You will have to be prepared to explain how to use the pH meter or probe to the class, so you may want to practice if you are new to this equipment.

- Immediately before class starts, set out the stands, clamps, glassware, wash bottles, and other equipment. Student pairs will send one person up to collect their equipment. Alternatively, set the equipment out on each lab bench.

- Provide each student pair (on request) with either 100 mL of 0.1 M HCl, or 100 mL of 0.1 M NaOH. Students will identify whether they need an acid or a base depending on the household substance(s) they have decided to titrate.

Part 1: Setting Up the Titration

Procedure

1. Have students collect their stands, clamps, glassware, and other equipment.

2. Instruct students to set up their equipment. Students can refer back to their set-up for their previous Hands-On Lab: Acid-Base Titrations.

3. Before handing out the chemicals, discuss the investigation with the class. Explain that:

   - Students will be choosing one or more household acids or bases to titrate. Ask: **How will you decide whether to use a solution of HCl or a solution of NaOH to titrate your household substance?** Answer: HCl will be used to titrate bases, and NaOH for acids.

   - Students will use pH meters or probeware along with graphing calculators or a graphing computer program to identify the equivalence point(s) of their titration. Take time to explain and if necessary demonstrate the use of pH meters or probeware and the graphing program to the class. Ask: **Why might it be better to use a pH meter or probeware instead of an indicator during a titration?** Answer: A pH meter or probeware allows for a more accurate identification of the endpoint.

   - Explain that the equivalence point of a titration can be seen on a graph of volume (x-axis) versus pH (y-axis). Sketch a titration curve on the blackboard. Point out the equivalence point halfway along the steepest part of the curve. Ask: **What happens at the molecular level when the equivalence point is reached?** Answer: the concentration of hydrogen ions in the solution is equal to the concentration of hydroxide ions in the solution.

   - Remind students that the equivalence point can arrive very quickly. As soon as students notice the pH is around 5 or 9 and starting to change more rapidly, they must slow down the volume being added to one or two drops at a time.
4. Give students time to choose their chemicals and come up with their own procedures. Check student procedures to make sure they are workable and safe.
5. Hand out the chemicals.
6. Have students prepare their burets by closing the stopcock at the bottom, placing an empty beaker under the bottom, and using a funnel to fill the buret partway. Remind students to eliminate any air bubbles by opening the stopcock and letting some solution flow out while gently tapping the side of the buret tip.
7. Depending on their procedure, students will use a pipette or graduated cylinder to add 100 mL of their household solution to a clean, dry 400 mL beaker. They will place a magnetic stirrer in the beaker, and position the beaker under the buret. If no magnetic stirrers are available, remind students to stir the solution manually after each addition of acid or base.
8. Students will rinse the pH electrode with distilled water, and place it in the beaker. If necessary, students can add distilled water to the household solution so that the pH meter or probeware can be placed out of the way of the magnetic stirrer. The addition of distilled water will not affect student calculations since they will be using the original volume (100 mL) for any calculations afterwards.
9. Students will ensure that the pH meter or probeware is turned on and functioning and the graphing program is turned on. The graph will record volume of HCl or NaOH on the x-axis, and pH on the y-axis.

Part 2: Carrying Out the Titration

Procedure

10. Students will record the starting volume of HCl or NaOH and the starting pH.
11. Students will follow their own procedure, gradually adding HCl or NaOH to the household solution at a rate of about 1 or 2 mL per addition. After each addition, students will stop and record the volume of acid or base and the pH. They will add these data to the graph.
12. Once the pH nears 5 or 9 (depending on whether the household substance is acidic or basic), students are getting closer to the equivalence point. They will start to observe the pH changing more rapidly. At this point, remind students to reduce the volume of each addition to one or two drops, and to use the wash bottle to rinse partial drops off the tip of the buret. Encourage students to continue past the equivalence point to produce a typical titration curve on their graph.
13. Students will repeat the titration a second time, using their graph from the first titration to estimate the volume of HCl or NaOH that is needed to exactly neutralize the household solution. They can start by adding the HCl or NaOH in larger installments this time, although they must slow down to a few drops when they get close to the estimated equivalence point.
14. If time permits, or if some student pairs finish before others, encourage students to plan and carry out a third titration using another household acid or base Have student pairs run their procedure past you before starting.
Part 3: Clean-up

Procedure

15. Have students empty their burets into their reaction beakers and rinse the burets with distilled water, adding the rinse to the reaction mixture as well. Have students rinse off the pH electrode or probeware with distilled water.
16. Collect student reaction mixtures and neutralize them if necessary. Dispose of the neutralized solutions in the appropriate waste containers.

Part 4: Calculations and Conclusions

Procedure

17. Students will use their titration graphs to identify the equivalence point of the titration: the midpoint of the most vertical part of the curve.
18. Have students answer the Analysis and Conclusions questions and the Additional Questions on the student sheet.
19. Students can work in pairs or groups to research the chemical formula of their household acid or base, and the neutralization reaction that took place during the titration. They will use this information to attempt to write a chemical equation for the reaction, and to calculate the concentration of their household acid or base. Note that some household acids and bases have complex chemical formulas, so be prepared to offer suggestions and to reward student efforts, even if they have difficulty coming up with an accurate answer.
20. Alternatively, or additionally, students can use the results of the titration to calculate the concentration of hydrogen ions their household solution was able to accept or donate. Have students calculate the concentration of hydrogen ions in the original solution using the pH of the original household solution. How might these two values be related to each other? Are they? Have a class discussion on the topic.
Analysis and Conclusions

1. How did you choose whether to use HCl or NaOH for your titration?

*If the household chemical was an acid, I used NaOH. If it was a base, I used HCl.*

2. Describe what you observed as you neared the equivalence point of your titration. How did you know when the equivalence point had been passed?

*As I neared the equivalence point the pH started to change faster. After adding just one drop, I got a large jump in pH. On the graph, the slope of the graph became very steep. I knew the equivalence point was past when the pH started increasing more slowly. On the graph, the slope evened out after the equivalence point.*

3. Some acids and bases have more than one equivalence point. Did you observe more than one equivalence point? What might be happening in a titration that has more than one equivalence point?

*I only observed one equivalence point (or, I observed more than one equivalence point; for example, citric acid in lemon juice is triprotic so more than one point may be observed). More than one equivalence point means that the acid has more than one proton to donate, or the base can accept more than one proton.*

4. Research the chemical formula and structure of the household acid or base you titrated. Use the formula (and further research if needed) to identify the chemical reaction that took place during the titration. If possible, write a chemical equation for the reaction and calculate the concentration of your household acid or base.

*For example, the chemical formula for pure white vinegar (acetic acid in water) is CH₃COOH. The chemical formula for baking soda is NaHCO₃. The chemical formula for the acid in lemon juice, citric acid, is C₆H₈O₇. Apple juice contains malic acid, C₄H₆O₅. Students can research the chemical structure of their compound and attempt to identify where hydrogen ions may be lost or gained. Students may have some difficulty calculating the concentration of their household compound, especially for triprotic acids like citric acid. Encourage students to follow the steps they learned from their previous titration lab to make the best approximation they can, even if an exact calculation is too advanced.*

5. How would you change your procedure if you did this investigation again? Why?

*For example, if I did this titration again, I would move more quickly up to pH 4, and then I would add increments of acid (or base) much more slowly. This time, I almost missed the equivalence point because I was adding acid too quickly.*
Additional Questions

1. (a) Write the chemical equation for a reaction between HCl and NaOH, both in aqueous solutions. Balance the equation if necessary. Identify each reactant and product.

$$\text{HCl}(aq) + \text{NaOH}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l)$$

_The reactants are hydrochloric acid and sodium hydroxide, a base. The products are sodium chloride, a salt, and water._

(b) What kind of reaction is this? How do you know?

_It is a neutralization reaction. The products of a neutralization reactant are a salt and water._

2. Describe what was happening in terms of ions and water molecules in each scenario:

(a) in the solution of HCl and water

_The hydrogen ion is dissociating and becoming surrounded by water molecules whose slightly negative ends are attracted to the hydrogen’s positive charge. At the same time, the chloride ion is being surrounded by water molecules whose slightly positive ends are attracted to its negative charge._

(b) in the solution of NaOH and water

_The sodium ion is dissociating and becoming surrounded by water molecules whose slightly negative ends are attracted to the sodium’s positive charge. At the same time, the hydroxide ion is being surrounded by water molecules whose slightly positive ends are attracted to its negative charge._

(c) in the reaction mixture when it was still mostly NaOH and water, after just a few drops of HCl solution were added

_The situation is the same as in (b), but there are a few chloride ions instead of none, and there are somewhat fewer hydroxide ions, as some have reacted with hydrogen ions to form water._

(d) in the reaction mixture at the equivalence point

_At the equivalence point, there are very few hydrogen ions and very few hydroxide ions, but they are present in exactly equal quantities. There are plenty of sodium and chloride ions, each surrounded by water molecules._

(e) in the reaction mixture after the equivalence point was passed

_There are more of one ion: either hydroxide or hydrogen, depending upon whether base or acid was being used to titrate._
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
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  - Design and conduct investigations using:
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    - Independent variable-the one variable the investigator chooses to change
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    - Constant-identify variables that must remain unchanged in multiple trials-repeated tests with the same variables to check for variability of results
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    - Following lab safety procedures
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    - Incorporating laboratory safety practices into the investigation design

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Balance
    - Pipette
    - Erlenmeyer flask
    - Graduated cylinder
    - Other Laboratory equipment
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
• Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
• What people expect to observe can affect how they perceive what they observe.
• Scientific investigations lead to the development of scientific explanations.
  o Scientific Data and Outcomes:
    • Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    • Comparisons of data are not accurate when some of the conditions are not kept the same.
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• Scientific Endeavor
  o Characteristics of Science:
    • Science is based on factual knowledge.
    • Scientists are curious about wanting to know how things work.
    • Scientific claims can be substantiated using data and observation.
    • Scientific theories are based on accumulated evidence.
    • Scientific knowledge is subject to modification as new information challenges prevailing theories and as a new theory leads to looking at old observations in a new way.
    • An important part of science is the critical review and analysis of any idea or conclusion.
• Engineering and Technology
  o Uses of Technology:
    • Not every problem has a technological solution.
Hands-On Lab
Solubility Rules

Timing: one 90-minute class session

Objective(s):
Students will develop their own solubility rules for ionic compounds through experimentation with a variety of compounds.

Safety Precautions:
- Students must wear safety equipment including goggles, gloves, and lab aprons.
- Any spills should be treated as though they are acid or base spills and should be handled by the teacher.
- Remind students to follow all general lab safety rules, wear closed-toe shoes, tie back hair, and not to eat or drink anything in the lab.
- Students should never leave the lab area unattended with chemicals sitting out.
- Students should follow all instructions for disposal and cleaning of the chemicals and their containers.
- Students should report any broken glass immediately and should not try to clean up any glass by themselves.

Materials:
Per group:
- Dropper bottles containing
  - 0.2 M KCl (50 mL)
  - 0.2 M KBr (50 mL)
  - 0.2 M KI (50 mL)
  - 0.2 M KOH (50 mL)
  - 0.2 M K₂SO₄ (50 mL)
  - 0.2 M K₂CO₃ (50 mL)
  - 0.2 M K₂S (50 mL)
  - 0.2 M NaNO₃ (50 mL)
  - 0.2 M Ca(NO₃)₂ (50 mL)
  - 0.2 M Pb(NO₃)₂ (50 mL)
  - 0.2 M AgNO₃ (50 mL)
  - 0.2 M NH₄NO₃ (50 mL)
- reaction plate, 48-well
- safety goggles, one pair per student
- lab apron, one per student
- disposable gloves, one pair per student
Teacher Preparation:
- Gather materials in advance of students performing the lab.
- While the lab can be performed having only one set of dropper bottles for an entire class, it will proceed more expeditiously if there are more than one set of dropper bottles.
- Remind students that they must not allow the tip of the dropper bottle to come into contact with any other solutions, or they will become contaminated.

Developing Solubility Rules

Procedure

1. Have students orient the well plate horizontally, so its wells are arranged in six rows and eight columns.
2. Next, students should label five of the rows with the cations Na\(^+\), Ca\(^{2+}\), Pb\(^{2+}\), Ag\(^+\), and NH\(_4\)\(^+\).
3. Then, students should label seven of the columns with the anions Cl\(^-\), Br\(^-\), I\(^-\), OH\(^-\), SO\(_4\)\(^{2-}\), CO\(_3\)\(^{2-}\), and S\(^2-\).
4. Students should make a table to record their observations, with the same number and labeling of rows and columns as on the well plate, as shown below.

<table>
<thead>
<tr>
<th>Anions</th>
<th>Cl(^-)</th>
<th>Br(^-)</th>
<th>I(^-)</th>
<th>OH(^-)</th>
<th>SO(_4)(^{2-})</th>
<th>CO(_3)(^{2-})</th>
<th>S(^2-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(^+)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb(^{2+})</td>
<td></td>
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<td></td>
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<tr>
<td>Ag(^+)</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>NH(_4)(^+)</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. In the row labeled Na\(^+\), students should place three drops of Na(NO\(_3\))\(_2\) in each of the wells. In a similar fashion, they should place three drops of the solution containing the labeled cation.
6. Then, starting with the column labeled Cl\(^-\), students should place three drops of the KCl solution in each of the rows that is filled with a cation solution. As they do so, they should carefully observe whether the solution remains transparent or becomes cloudy. The cloudy solutions represent insoluble compounds. Students should record their information in their table.
7. Students should continue the process in subsequent columns with solutions containing the anion that matches that column’s labels.
8. When the lab is completed, students should dispose of the solutions and precipitates as you direct, based on your school’s rules and your local area’s regulations on chemical disposal.

Sample Data

<table>
<thead>
<tr>
<th>Anions</th>
<th>Cl(^-)</th>
<th>Br(^-)</th>
<th>I(^-)</th>
<th>OH(^-)</th>
<th>SO(_4)(^{2-})</th>
<th>CO(_3)(^{2-})</th>
<th>S(^2-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(^+)</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
<tr>
<td>Pb(^{2+})</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
<tr>
<td>Ag(^+)</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
<td>ppt</td>
</tr>
<tr>
<td>NH(_4)(^+)</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
<td>no ppt</td>
</tr>
</tbody>
</table>
Analysis and Conclusion

1. As you move across one row of the well plate, what are the independent and the dependent variables?

As you move across one row of the well plate, the same cation is being tested separately with several different anions (the independent variable). The dependent variable is the solubility of the combination.

2. As you move down one column of the well plate, what are the independent and the dependent variables?

As you move down one column of the well plate, the same anion is being tested separately with several different cations (the independent variable). The dependent variable is the solubility of the combination.

3. When the solutions were combined, each well plate contained two different anions and two different cations. Explain how you can now which anion and cation were actually forming the precipitate.

Because none of the original solutions contained precipitates, you know that the combinations of ions they contain are soluble.

4. What do your observations tell you about compounds containing potassium cations?

Compounds containing potassium cations and any of the anions tested are always soluble.

5. What do your observations tell you about compounds containing nitrate anions?

Compounds containing nitrate anions and any of the cations tested are always soluble.

6. Are there any other cations or anions that always form soluble compounds? Write a solubility rule that describes these observations.

Compounds containing ammonium cations and any of the anions tested are always soluble.

7. Which cations formed the most precipitates? Write a solubility rule that describes this observation, taking into account any exceptions.

Compounds containing silver or lead cations and any of the anions tested are insoluble, except nitrate, which is soluble.

8. Which cation formed some precipitates with some anions, but not with others? Write a solubility rule that describes this observation.

Compounds containing calcium cations are insoluble, except for nitrate, chloride, bromide, and iodide.
9. Using your solubility rules, predict whether a precipitate will form when the following solutions are combined. If a precipitate is formed, give its formula.
   a. NaOH and CaI
   b. Pb(NO₃)₂ and Na₂SO₄
   c. AgNO₃ and NH₄Br
   d. Ca(NO₃)₂ and NaCl

   a. Precipitate, Ca(OH)₂
   b. Precipitate, PbSO₄
   c. Precipitate, AgBr
   d. No precipitate
In this lab, students will demonstrate the following Inquiry Skills:

- **Identify**
  - Develop predictions hypotheses:
    - state what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design investigations**
  - Design and conduct investigations using:
    - Independent variable – the one variable the investigator chooses to change
    - Dependent variables – what changes as a result of, or in response to, the change in the independent variable
  - Practice lab safety by:
    - Following lab safety procedures

- **Gather Data**
  - Use senses to observe
    - Seeing (color, shape, size, texture, motion)
  - Uses the appropriate format to record date:
    - Table

- **Interpret Data**
  - Identifies and interprets patterns
    - Trends in data
    - Tables and graphs
    - Analyzes data collected during an investigation

- **Evaluate Evidence**
  - Drawing and supporting a conclusion by:
    - Reporting out trends and patterns in the data
  - Assessing the conclusion by:
    - Extrapolating results beyond the investigation

- **Communication in Science**
  - Report results using:
    - Table/graph showing data
1. Hydrofluoric acid, HF, dissociates according to the following equation.

\[
\text{HF(aq)} \rightleftharpoons \text{H}^+(\text{aq}) + \text{F}^-(\text{aq})
\]

The equilibrium constant, \( K_{eq} \), for this system is \( 7.21 \times 10^{-4} \) at 25°C, and the equilibrium concentrations are: \([\text{HF}] = 0.974 \text{ M}, [\text{H}^+] = 0.0265 \text{ M}, \text{ and } [\text{F}^-] = 0.0265 \text{ M} \). If the concentration of HF is increased by 0.50 M, what will be the new concentrations of \( \text{H}^+ \) and \( \text{F}^- \)?

[answer:

<table>
<thead>
<tr>
<th>Initial</th>
<th>[HF]</th>
<th>[H⁺]</th>
<th>[F⁻]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.974 + 0.50</td>
<td>0.0265</td>
<td>0.0265</td>
</tr>
</tbody>
</table>

| Change | x | x | x |

| Equilibrium | 1.474 - x | 0.0265 + x | 0.0265 + x |

\[
K_{eq} = 7.21 \times 10^{-4} = (0.0265 + x)(0.0265 + x)/(1.474 - x) \approx (0.0265 + x)^2/1.474
\]

\[
1.06 \times 10^{-3} = 7.02 \times 10^{-4} + 0.053x + x^2
\]

\[
x^2 + 0.053x - 3.61 \times 10^{-4}
\]

\[
x = 6.11 \times 10^{-3} \text{ or } -0.059 \times 10^{-2}; x \text{ will be positive}
\]

\[
[H^+] = [F^-] = 0.0265 + x = 0.0265 + 0.00611 = 0.0326 \text{ M}
\]

2. The equilibrium constant for the following reaction is \( 1.00 \times 10^{-2} \) at the relevant temperature.

\[
2\text{HI(g)} \rightleftharpoons \text{H}_2\text{(g)} + \text{I}_2\text{(g)}
\]

Data for concentrations at equilibrium are given in the table below.

<table>
<thead>
<tr>
<th>[HI] (mol/L)</th>
<th>[H₂] (mol/L)</th>
<th>[I₂] (mol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0830</td>
<td>0.0083</td>
<td>0.0083</td>
</tr>
<tr>
<td></td>
<td>[HI]</td>
<td>[H₂]</td>
</tr>
<tr>
<td>--------</td>
<td>-----------</td>
<td>-----------</td>
</tr>
<tr>
<td>Initial</td>
<td>0.083 + 0.1000</td>
<td>0.0083</td>
</tr>
<tr>
<td>Change</td>
<td>− 2x</td>
<td>x</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>0.1830 − 2x</td>
<td>0.0083 + x</td>
</tr>
</tbody>
</table>

\[
K_{eq} = 1.00 \times 10^{-2} = \frac{[H_2][I_2]}{[HI]^2} = \frac{(0.0083 + x)(0.0083 + x)}{(0.1830 − 2x)^2}
\]

\[
1.00 \times 10^{-2} = \frac{(6.89 \times 10^{-5} + 0.0166x + x^2)/(0.033 − 0.73x + 4x^2)}{3.35 \times 10^{-4} − 7.32 \times 10^{-3}x + 0.04x^2 = 6.89 \times 10^{-5} + 0.0166x + x^2}
\]

\[
x = 0.0083 \text{ or } −0.033; \ x \text{ will be positive}
\]

\[
[H^+] = [I^-] = 0.0083 + x = 0.0083 + 0.0083 = 0.0166 \text{ M}
\]

3. Consider the following system:

\[2 \text{HOCl}(g) \leftrightarrow \text{H}_2\text{O}(g) + \text{ClO}_2(g)\]

At equilibrium, the concentration of each component is: [HOCl] = 0.040 M, [H₂O] = 0.230 M, and [ClO₂] = 0.230 M. If the concentration of HOCl is increased by 0.050 M from the equilibrium conditions, what will be the new concentrations of H₂O and ClO₂ once the system returns to equilibrium?

<table>
<thead>
<tr>
<th></th>
<th>[HOCl]</th>
<th>[H₂O]</th>
<th>[ClO₂]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0.040 + 0.050</td>
<td>0.230</td>
<td>0.230</td>
</tr>
<tr>
<td>Change</td>
<td>− 2x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>0.090 − 2x</td>
<td>0.230 + x</td>
<td>0.230 + x</td>
</tr>
</tbody>
</table>

\[
K_{eq} = \frac{[\text{H}_2\text{O}][\text{ClO}_2]}{[\text{HOCl}]^2} = \frac{(0.230)(0.230)/(0.040)^2} = 33.1
\]

\[
33.1 = \frac{(0.230 + x)(0.230 + x)}{(0.090 − 2x)^2}
\]

\[
33.1 = \frac{(0.0529 + 0.46x + x^2)/(0.0081 − 0.36x + 4x^2)}{0.268 − 11.9x + 132x^2 = 0.0529 + 0.46x + x^2}
\]

\[
131x^2 − 11.4x + 0.215 = 0
\]

\[
x = 0.059 \text{ or } 0.028; \text{ the change in } 2x \text{ cannot be greater than } 0.090
\]

\[
[H_2O] = [ClO_2] = 0.230 + x = 0.230 + 0.028 = 0.258 \text{ M}
\]

4. Household ammonia is a solution of ammonia in water. In this solution, ammonia reacts with water to form ammonium hydroxide, which ionizes according to the equation below. At 298K, \(K_{eq} = 1.8 \times 10^{-5}\) for this reaction.

\[\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(l) \leftrightarrow \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})\]

The effectiveness of the cleaner decreases as the amount of ammonia in the solution decreases. However, the cost to produce the solution increases when more ammonia
Changing Concentration

is added. Solution A was made using \([\text{NH}_3] = 7.2 \times 10^{-3}\) M. In Solution B, \([\text{NH}_4^+] = 5.2 \times 10^{-4}\) M. Which solution cleans better? Which solution is less costly to produce? Explain your answers in terms of the amount of ammonium in the solutions.

[answer:

Solution A

<table>
<thead>
<tr>
<th></th>
<th>[NH\textsubscript{3}]</th>
<th>[\text{NH}_4^+]</th>
<th>[\text{OH}^-]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>7.2 \times 10^{-3}</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>(x)</td>
<td>(x)</td>
<td></td>
</tr>
<tr>
<td>Equilibrium</td>
<td>7.2 \times 10^{-3} – (x)</td>
<td>0 + (x)</td>
<td></td>
</tr>
</tbody>
</table>

\(K_{\text{eq}} = 1.8 \times 10^{-5} = x^2/(7.2 \times 10^{-3} – x) \approx x^2/7.2 \times 10^{-3}
\(x^2 = (1.8 \times 10^{-5})(7.2 \times 10^{-3}) = 1.3 \times 10^{-7}
\(x = (1.3 \times 10^{-7})^{1/2} = 3.6 \times 10^{-4}

Is approximation valid? \((3.6 \times 10^{-4})(7.2 \times 10^{-3}) \times 100 = 5\%\), so approximation is valid.

A solution made using \([\text{NH}_3] = 7.2 \times 10^{-2}\) M, produces \([\text{NH}_4^+] = 3.6 \times 10^{-4}\) M. A higher starting concentration of ammonia will produce more ammonium in solution, which means the ammonia concentration used to make Solution B was greater than Solution A. Therefore, Solution B cleans better, but Solution A is less costly to produce.]

5. Carbonated beverages contain bubbles of carbon dioxide that make the beverage fizzy. However, these beverages also contain carbonic acid, which can slowly wear away the enamel of the teeth of people who drink them. When carbon dioxide reacts with water, it reacts to form carbonic acid. Carbonic acid then dissociates, as shown by the set of equations below.

\[
\text{CO}_2(aq) + \text{H}_2\text{O}(l) \leftrightarrow \text{H}_2\text{CO}_3(aq)
\]

\[
\text{H}_2\text{CO}_3(aq) + \text{H}_2\text{O}(l) \leftrightarrow \text{H}_3\text{O}^+(aq) + \text{HCO}_3^-(aq)
\]

The equations can be combined.

\[
\text{CO}_2(aq) + 2\text{H}_2\text{O}(l) \leftrightarrow \text{H}_3\text{O}^+(aq) + \text{HCO}_3^-(aq) 
K_{\text{eq}} = 4.6 \times 10^{-7}
\]

If \([\text{CO}_2] = 0.15\) M in a sealed carbonated beverage, what is the concentration of hydronium ions in the soda? Assume no other acids are added. As bubbles escape from the beverage after it is opened, the \([\text{CO}_2]\) decreases to \(1.5 \times 10^{-5}\). What happens to the concentration of the hydronium ions in the beverage? Although “flat” beverages might not taste as good, would they be less damaging to teeth?
Unopened

<table>
<thead>
<tr>
<th></th>
<th>$[\text{H}_3\text{O}^+]$</th>
<th>$[\text{HCO}_3^-]$</th>
<th>$[\text{CO}_2]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0</td>
<td>0</td>
<td>0.15</td>
</tr>
<tr>
<td>Change</td>
<td>$x$</td>
<td>$x$</td>
<td>$-x$</td>
</tr>
<tr>
<td>Equilibrium</td>
<td>$0 + x$</td>
<td>$0 + x$</td>
<td>$0.15 - x$</td>
</tr>
</tbody>
</table>

$K_{eq} = 4.6 \times 10^{-7} = \frac{x^2}{(0.15 - x)} \approx \frac{x^2}{0.15}$

$x^2 = (4.6 \times 10^{-7})(0.15) = 6.9 \times 10^{-8}$

$x = (6.9 \times 10^{-8})^{1/2} = 2.63 \times 10^{-4}$

$[\text{H}_3\text{O}^+] = 2.63 \times 10^{-4}$ M

A decrease in $[\text{CO}_2]$ means the initial concentration decreases and the $[\text{H}_3\text{O}^+]$ at equilibrium will be much less. After losing carbon dioxide gas, the beverage is now less acidic and might be less damaging to the teeth.
Exploration Teacher Guide: Chemical Equilibrium

Overview

According to Le Châtelier’s principle, if a system at equilibrium undergoes a change, the equilibrium shifts in a direction that opposes the introduced change. In this Exploration, students verify Le Châtelier’s principle for concentration, temperature and pressure.

Student Learning Objectives

- Analyze the effect of change in concentration, temperature, and pressure on chemical equilibrium.
- Observe the shift in equilibrium for various reactions depending on different parameters.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Explore tab, a beaker is displayed on the left. On the right, a zoomed in view shows the contents of the beaker on a molecular scale. A chemical reaction represents the equilibrium state of the beaker contents. Students select one of the parameters, concentration, temperature, or pressure, using the Select Parameter dropdown list. Upon selection of the parameter, the Select Action section displays two radio button options. A different reaction is provided for each of the parameters.

When the student clicks one of the Select Action options, the Start button is highlighted. When the student clicks the Start button, the zoomed in view shows the reactant and product molecules in motion. The selected action causes a shift in equilibrium. Students are then asked to determine the direction of equilibrium shift.

Using the Reset button students can reset the Exploration and observe the values for a different selection.

The Tracker tab displays a summary of the values for all the runs. Students can observe the direction of equilibrium shift for the selected action and the number of molecules that result from the selected change.

Answers to Questions in the Student Worksheet

1. Using this Exploration, explain why increasing pressure shifts the equilibrium to the left direction in favor of the formation of ammonia.
Answer: According to Le Châtelier’s principle, if pressure is increased the reaction will proceed in a direction that reduces pressure. As applied pressure increases, the reaction proceeds in the reverse direction so that hydrogen and nitrogen combine to form ammonia. This results in a decrease in the number of hydrogen and nitrogen molecules. Hence, an equilibrium shift to the left in favor of ammonia formation reduces the total pressure of the cylinder.

2. Explain Le Châtelier’s principle along with an example.

Answer: Le Châtelier’s principle states that “If stress is applied to a system at equilibrium, the system shifts in the direction that relieves the stress.”
Example: If you add reactants (stress applied) to a system at chemical equilibrium, the number of products increase (stress relieved).

3. Using this Exploration, explain why removing Fe$^{3+}$ shifts the equilibrium to the right direction.

Answer: According to Le Châtelier’s principle if concentration of products is decreased, the reaction will proceed in a direction that increases the concentration of the products. As Fe$^{3+}$ is removed, iron thiocyanate dissociates to form more Fe$^{3+}$ and restore equilibrium in the system.

4. Consider an exothermic chemical reaction at equilibrium: $A + 2B \rightleftharpoons C + D$. Determine which of the following actions should be performed to increase the amount of D produced.

   a. Increase the temperature.
   b. Decrease the temperature.
   c. Increase concentration of C.
   d. Increase concentration of B.

Answer: Performing actions mentioned in options b and d will increase the amount of D produced.

5. Determine the equilibrium shift in the following cases.

   a. Concentration of reactants is increased.
   b. Concentration of products is decreased.
   c. Concentration of reactants is decreased.
   d. Concentration of products is increased.
Answer:

a. Equilibrium shifts in the direction of products.

b. Equilibrium shifts in the direction of products.

c. Equilibrium shifts in the direction of reactants.

d. Equilibrium shifts in the direction of reactants.

6. Explain whether an increase or decrease in volume affects the equilibrium.

Answer: Changing the volume of the solution has the same effect as changing the concentration of the reactants or products. If volume is reduced, the concentration of reactants and products increases. According to Le Châtelier's principle, the system reacts in a way that opposes this change so that the effective change in concentration is neutralized.

7. For the chemical reaction \( \text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g) \), explain how letting the gas (formed as a product) escape will help in increasing the amount of \( \text{CaO} \) produced.

Answer: The chemical equation for this reaction is \( \text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g) \). In this reaction \( \text{CO}_2 \) (gas) is formed as a product. If arrangements are made for \( \text{CO}_2 \) to escape, its concentration will decrease. The reaction will produce more \( \text{CO}_2 \) to oppose this change and regain equilibrium. Since \( \text{CaO} \) is also a product in the reaction, the amount of \( \text{CaO} \) produced will also increase.

8. Does adding a catalyst to a chemical reaction at equilibrium change the concentration of reactants or products? Explain.

Answer: A catalyst increases the rate of reaction in both, the forward and reverse directions. So there is no resultant shift in the equilibrium of the reaction. The reaction reaches equilibrium at a faster rate.

9. Explain how increasing the temperature of an endothermic chemical reaction affects the direction in which its equilibrium shifts. Compare the equilibrium shift with decreasing the temperature of an endothermic reaction.

Answer: Increasing the temperature of an endothermic reaction shifts the reaction toward the products. This implies that more products are produced. If the temperature of an endothermic reaction is decreased, the reaction shifts toward the reactants.
10. For a reversible chemical reaction, are the following statements true or false?

a. Change in surface area of the reactants shifts the equilibrium to the right direction.

b. No chemical reaction occurs when a system is at chemical equilibrium.

Answer:

a. False. Change in surface area only affects the rate of reaction.

b. False. Chemical reaction occurs when a system is at chemical equilibrium. The rate of forward and reverse reaction is equal and so the concentration of reactants and products does not vary.
Hands-On Lab
Color Changes in Equilibrium Systems

**Timing:** one 90-minute class session

**Objective(s):**
The objective of this experiment is to gain an understanding of how equilibrium reactions are affected by changes. The student will learn how to apply Le Chatelier’s principle to understand and relate observed changes in an equilibrium mixture. They will discover the effect of different types of stressors on a reversible reaction.

**Safety Precautions:**
Remind the students that during the lab experiment, all directions must be followed. Students will be working with chemicals, so ensure that they do not eat or drink in the lab. 6M HCl is a strong acid and is very corrosive; have some baking soda nearby in case of an acid spill. Handle all chemicals with care. If any chemical is spilled onto skin, rinse with water for at least 10 minutes. Remind students that care should be taken when using a flame or hot plate as nearby items can ignite. Make sure proper attire is always worn, including closed-toed shoes, eye protection, lab aprons, and gloves. After the lab is complete, dispose of all chemicals properly.

**Materials:**
Per group of 2-3 students:

- beakers (2)
- glass stirring rod
- graduated cylinder, 50 or 100 mL
- ice
- pipette or dropper
- stir plate or hot plate
- test tubes (10)
- test tube holder
- water
- 0.1M AgNO₃ (17 g AgNO₃ in 1L water)
- 0.2M CoCl₂ (26 g of CoCl₂ in 1L water)
- 6M HCl
- NaCl, solid

**Teacher Preparation:**
The reversible reaction for this experiment is:

\[
[\text{CoCl}_4]^{2-}(\text{aq}) + 6\text{H}_2\text{O}(l) \leftrightarrow [\text{Co(H}_2\text{O})_6]^{2+}(\text{aq}) + 4\text{Cl}^- (\text{aq}) + \text{heat}
\]

(blue) (pink)
To help ensure this lab can be completed in 90 minutes, set up the materials and equipment ahead of time. It may be most efficient to set up three stations for students to use as they collect data.

Prepare the CoCl₂ solution beforehand by dissolving 26 g CoCl₂ in 1 liter of water. For the hot water bath, set up a hot plate and place a 100 mL or 200 mL beaker full of water on it. For the ice bath, set up a 100 mL or 200 mL beaker half full of water and half full of ice.

Print enough copies of the Student Investigation Sheet to ensure enough for each student.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Directed Inquiry**

Begin the lab with an introduction to the experiment that will be performed. First, describe the reversible reaction in this experiment and post the equation as written below.

\[
[\text{CoCl}_4]^{2-}(\text{aq}) + 6\text{H}_2\text{O}(l) \leftrightarrow [\text{Co(H}_2\text{O})_6]^{2+}(\text{aq}) + 4\text{Cl}^-(\text{aq})
\]

Note that the initial solution should be pink-purple. Point out that when the reaction above is shifted toward the reactants, the color of the solution will turn bluer, but when the reaction is shifted more toward the product, it will become pinker. Ask students what kinds of stress can be applied to the system in order to shift the reaction one way or another. (changes in concentration, changes in temperature, changes pressure/volume) Explain that this lab is not developed to investigate the effect of changing pressure or volume.
Explain that adding HCl to the initial CoCl$_2$ solution involves adding Cl$^-$ ions to the reaction. It should shift the reaction toward the reactants.

Have students complete the following procedure:

1. Place 10 test tubes in a test tube rack and label them 1-10.
2. Add 3-5 mL (60-100 drops) of 0.2M CoCl$_2$ to each test tube.
3. Note the initial color of the solution in the table. (The solution in each tube should be the same color, pink-purple).
4. The first test tube will serve as the control. Nothing should be added to this tube.
5. Add 10-20 drops of 6M HCl to test tube 2.
6. Record the color (light blue).
7. Heat test tube 3 in boiling water for 2-3 minutes.
8. Record the color (light blue).
9. Place test tube 4 in ice for 5-10 minutes.
10. Record the color (pink).

**Guided Inquiry**

Explain to students that they will conduct similar investigations using different compounds and other strategies of their choosing to shift the equilibrium of the chemical system. Point out the materials you have available for them to use. Note that adding NaCl to the initial CoCl$_2$ solution involves adding Cl$^-$ ions to the reaction. Conversely, note that adding AgNO$_3$ to the initial CoCl$_2$ solution is like removing Cl$^-$ ions from the reaction.

If necessary, provide questions to help the students guide their inquiry?

- What prediction can you make about the results that occur when different compounds are added to CoCl$_2$?
- How will adding reactant and/or product change the equilibrium of the system?
- How can you use your observations to determine if a reaction is exothermic or endothermic?

If necessary, you might want to explain to students that this can be done by adding heat to the products. When the temperature is raised, the equilibrium should shift toward reactants; conversely, when the temperature is lowered, the equilibrium should shift toward products.

Have student groups design their procedures and, after teacher approval, conduct the investigation.

**Sample procedures:**

1. Add a few grains of NaCl, enough to almost saturate solution, to test tubes 5, 6 and 7.
2. The fifth test tube will serve as a control. Nothing more should be added to this tube.
3. Record the color of the three test tubes (blue).
4. Place test tube 6 in boiling water for 2-3 minutes.
5. Record the color (darker blue).
6. Place test tube 7 in the ice for 5-10 minutes.
7. Record the color (pink or lighter blue).
8. Add 20-25 drops of 0.1M AgNO₃ to test tubes 8, 9, and 10 (removing Cl⁻).
9. The eighth test tube will serve as a control. Nothing more should be added to this tube.
10. Record the color of the test tubes (pink).
11. Place test tube 9 in boiling water for 2-3 minutes.
12. Record the color (pink or light blue).
13. Place test tube 10 in the ice for 5-10 minutes.
14. Record the color (darker pink).

Sample table: Have the students record their observations in a data table or other organized format.

<table>
<thead>
<tr>
<th></th>
<th>Initial</th>
<th>HCl</th>
<th>Heat</th>
<th>Cold</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1) 0.2M CoCl₂</strong></td>
<td>[pink]</td>
<td>[light blue]</td>
<td>[darker blue]</td>
<td>[pink]</td>
</tr>
<tr>
<td><strong>2) 0.2M CoCl₂ + NaCl</strong></td>
<td>[blue]</td>
<td></td>
<td>[darker blue]</td>
<td>[lighter blue or pink]</td>
</tr>
<tr>
<td><strong>3) 0.2M CoCl₂ + AgNO₃</strong></td>
<td>[pink]</td>
<td>[light pink/light blue]</td>
<td></td>
<td>[darker pink]</td>
</tr>
</tbody>
</table>
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. Consider the following equation:
   \[ [\text{CoCl}_4]^{2-} (aq) + 6H_2O(l) \leftrightarrow [\text{Co(H}_2\text{O})_6]^{2+} (aq) + 4\text{Cl}^- (aq) \]
   (blue) (pink)

   What happens when NaCl is added? Cl\textsuperscript{−} ion is being added when NaCl is added. The addition of one of the species in the reaction will drive a reversible reaction away from the addition of the species. Thus, adding Cl\textsuperscript{−} ion will shift the reaction toward the products. This gives the solution a blue color.

2. What happens during the experiment when AgNO\textsubscript{3} is added? When AgNO\textsubscript{3} is added, the precipitate AgCl forms. Since this reaction reduces the Cl\textsuperscript{−} ion (a species in the reactants), to regain equilibrium more of the species that is being removed will form. This will drive the reaction in the direction of the Cl\textsuperscript{−} ion, or toward the products, and will give the solution a pink color.

3. Based on your results, which direction of the reversible reaction is exothermic? Which is endothermic? How do you know?
   The forward reaction, in which the product is pink, is the exothermic reaction. This was shown when the tube was placed in ice (the temperature decreased). When temperature decreases, the equilibrium shifts in the exothermic direction. In this case, the compound in the tube turned pink when the system was placed in ice, which indicated a shift toward the products. Conversely, when heated the tube turned blue, showing a shift toward the reactants.

4. Provide another way the equilibrium of this reaction can be shifted. Indicate the direction the equilibrium will shift and the color the solution will turn.
   If you add more [CoCl\textsubscript{4}]\textsuperscript{2−} the reaction will shift toward the products and turn pinker. If the solution is diluted, this will also shift the reaction to the products and the solution will turn pink. It may be more difficult to do, but you can change the pressure/volume of the reaction. Lower pressure will shift the equilibrium to the reactants because there are more moles of reactant than product, and the solution will turn blue. Higher pressure will shift the reaction toward the products because there are fewer moles on the product side of the reaction, and the solution will turn pink.

5. When the reaction is heated, would you expect that value of the equilibrium constant to increase, decrease, or stay the same? Explain your answer. When the reaction is heated, it drives the reaction to the reactants side of the equation. Since \( K_{eq} = \frac{[\text{products}]}{[\text{reactants}] } \), if the concentration of reactants increases, the \( K_{eq} \) should decrease.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- Design Investigations
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Control (control group) - used for comparison in which the independent variable is not changed
  - Practice lab safety by:
    - Following lab safety procedures

- Gather Data
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
    - Bunsen burner
    - Pipette
    - Graduated cylinder
    - Test tube
    - Hot plates
  - Use senses to observe:
    - Seeing (color, shape, size, texture, motion)
  - Use the appropriate format to record data:
    - Table

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Comparing results to hypothesis

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating a conclusion
• Scientific Investigation
  o Scientific Investigation:
    ▪ Science investigation begins with a testable question.
    ▪ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
  o Scientific Data and Outcomes:
    ▪ It is important in science to keep honest, clear, and accurate records.
• Scientific Endeavor
  o Characteristics of Science:
    ▪ Scientists are curious about how things work.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Concept: Chemical Equilibrium

Overview: You will work through the Explore of the concept Chemical Equilibrium. As you proceed, you will highlight important terms. You will research the meaning of these terms. With a partner, you will create flashcards

Directions:

1. Use the interactive glossary to find out about the terms "evaporation," "condense," and "freeze."
2. With a partner, make a flash card for each term.
3. Go through the rest of the Explore section. Highlight important terms.
4. With your partner, develop flashcards for these.
5. Use the flashcards to test other students on their understanding of these terms.

What parts of the Techbook are you using? ________________________________

Who are you working with?

the whole class a group one other person nobody

What will you have when you finish? ________________________________

Before you make the flashcards, record the terms and their meanings below.

<table>
<thead>
<tr>
<th>Term</th>
<th>Meaning</th>
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<tbody>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>Vocabulary Term</td>
<td>Meaning</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
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<td></td>
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</tr>
</tbody>
</table>
Hands-On Activity
Mystery Solubility Product Constants

Objective:
In this activity, students will apply their knowledge of solubility product constants as they write the solubility product equation and then use the equation to determine if a precipitate will form during a reaction.

Estimated time to complete: 20 minutes

Materials:
For each group of 2-3 students:
- 2 containers such as paper bags or bowls, one labeled “anion” and the other labeled “cation”
- Cards listing solubility product constants
- Cards listing concentration values
- Worksheet: Mystery Solubility Product Constants

Procedure:
In this activity, students will place the cards that contain the solubility product constants into one container and the cards showing concentration values into another container. Instruct the students to begin the activity by pulling one of the solubility product constant cards (Card 1) from the container. Have the student write the solubility product constant in the worksheet under “K_{sp}” and the formula for the solid under the column “Formula.” Next, have the students write the expression for the solubility product in the third cell under “K_{sp Expression}” for the substance on Card 1.

Then have the students pull two cards out of the second container. The first of these cards (Card 2) is the concentration of the cation in the reaction. The second card (Card 3) is the concentration of the anion. Have the students write these values in the table under “[Cation]” and “[Anion]” and then use these values in the solubility product expression to determine if a precipitate will form during the reaction. Indicate if a precipitate does form under the last column “Precipitate?”

Remind students that an unsaturated solution has an ion product value less than the value of K_{sp}, while a saturated solution has an ion product value equal to K_{sp}. In both of these cases, a precipitate will not form. However, when the ion product value exceeds K_{sp}, the solution becomes supersaturated and a precipitate forms.

Have the student groups each complete at least eight solubility product calculations and input the values into the worksheet.
### Solubility Constant Cards:

<table>
<thead>
<tr>
<th>Compound</th>
<th>K&lt;sub&gt;sp&lt;/sub&gt;</th>
<th>Compound</th>
<th>K&lt;sub&gt;sp&lt;/sub&gt;</th>
<th>Compound</th>
<th>K&lt;sub&gt;sp&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>PbBr&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$6.6 \times 10^{-6}$</td>
<td>CuBr</td>
<td>$6.3 \times 10^{-9}$</td>
<td>AgBr</td>
<td>$5.4 \times 10^{-13}$</td>
</tr>
<tr>
<td>MgCO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>$6.8 \times 10^{-6}$</td>
<td>NiCO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>$1.3 \times 10^{-7}$</td>
<td>CaCO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$5.0 \times 10^{-9}$</td>
</tr>
<tr>
<td>PbCl&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$1.2 \times 10^{-5}$</td>
<td>CuCl</td>
<td>$1.7 \times 10^{-7}$</td>
<td>BaF&lt;sub&gt;3&lt;/sub&gt;</td>
<td>$1.8 \times 10^{-7}$</td>
</tr>
<tr>
<td>MgF&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$7.4 \times 10^{-11}$</td>
<td>AgCO&lt;sub&gt;3&lt;/sub&gt;</td>
<td>$8.1 \times 10^{-12}$</td>
<td>Ag&lt;sub&gt;3&lt;/sub&gt;PO&lt;sub&gt;4&lt;/sub&gt;</td>
<td>$8.9 \times 10^{-17}$</td>
</tr>
<tr>
<td>Mn&lt;sub&gt;3&lt;/sub&gt;(PO&lt;sub&gt;4&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$1.0 \times 10^{-22}$</td>
<td>Fe(OH)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$4.9 \times 10^{-17}$</td>
<td>Pb&lt;sub&gt;3&lt;/sub&gt;(PO&lt;sub&gt;4&lt;/sub&gt;)&lt;sub&gt;2&lt;/sub&gt;</td>
<td>$7.9 \times 10^{-43}$</td>
</tr>
</tbody>
</table>
### Concentration Value Cards:

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 \times 10^{-6}</td>
<td>3.5 \times 10^{-2}</td>
<td>1.6 \times 10^{-3}</td>
</tr>
<tr>
<td>1.4 \times 10^{-1}</td>
<td>5.6 \times 10^{-8}</td>
<td>4.7 \times 10^{-10}</td>
</tr>
<tr>
<td>2.4 \times 10^{-13}</td>
<td>4.6 \times 10^{-7}</td>
<td>1.1 \times 10^{-11}</td>
</tr>
<tr>
<td>2.8 \times 10^{-2}</td>
<td>7.5 \times 10^{-10}</td>
<td>4.7 \times 10^{-4}</td>
</tr>
<tr>
<td>8.3 \times 10^{-12}</td>
<td>9.2 \times 10^{-4}</td>
<td>3.4 \times 10^{-6}</td>
</tr>
<tr>
<td>2.6 \times 10^{-8}</td>
<td>3.2 \times 10^{-2}</td>
<td>8.8 \times 10^{-1}</td>
</tr>
<tr>
<td>3.0 \times 10^{-3}</td>
<td>8.5 \times 10^{-4}</td>
<td>4.3 \times 10^{-2}</td>
</tr>
<tr>
<td>9.2 \times 10^{-3}</td>
<td>8.3 \times 10^{-2}</td>
<td>8.1 \times 10^{-5}</td>
</tr>
<tr>
<td>7.1 \times 10^{-4}</td>
<td>1.2 \times 10^{-1}</td>
<td>9.5 \times 10^{-4}</td>
</tr>
</tbody>
</table>
**Worksheet: Mystery Solubility Product Constants**

<table>
<thead>
<tr>
<th>$K_{sp}$</th>
<th>$K_{sp}$ Expression</th>
<th>[Cation]</th>
<th>[Anion]</th>
<th>Precipitate?</th>
</tr>
</thead>
<tbody>
<tr>
<td>$[6.6 \times 10^{-6}]$</td>
<td>$K_{sp} = [Pb^{2+}][Br^-]^2$</td>
<td>$[3.0 \times 10^{-3}]$</td>
<td>$[8.1 \times 10^{-5}]$</td>
<td>[No, product is $1.9 \times 10^{-11}$]</td>
</tr>
</tbody>
</table>
Inquiry and Nature of Science Skills in this Activity:

- **Design Investigations**
  - Make or use models that:
    - Apply mathematical operations and principles to replicate the real thing.

- **Gather Data**
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Sort and classify using scientific reasoning by:
    - Sorting objects, substances and organisms by characteristic
  - Identify and interpret patterns using:
    - Tables and graphs

- **Communication in Science**
  - Report results using:
    - Scientific explanations/arguments
    - Table/graph showing data

- **Analyze Scientific Results**
  - Participate in critiquing/peer review by:
    - Evaluating a conclusion

- **Scientific Endeavor**
  - Characteristics of Science:
    - Scientists are curious about wanting to know how things work.
    - One way to make sense of something is to think of how it relates to something more familiar.
    - Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.
Hands-On Activity
Pennies in Equilibrium

Objective:
To explore the changes and consistencies within a system in equilibrium

Estimated time to complete: 10 minutes

Materials:
For each student:
- 24 pennies

Procedure:
Provide each student with 24 pennies. Have the students divide the pennies into groups so that all the groups contain the same amount of pennies. For example, they might create 2 groups of 12, 3 groups of 8, four groups of 6, 8 groups of 3, 6 groups of 4, or 12 groups of 2. Ask students to describe what is similar and what is different about each group. (The type and number of items in each group are the same, but the individual items in each group are each a bit unique.)

Next, ask students how the groups of pennies might be changed without changing the overall structure of the system. If necessary, guide students to move one penny from each group to the next so that each group donates one penny and each group receives one penny.

Ask the students to identify what has changed in each group. (The groups don't contain the same pennies they started with. The number of pennies in each group is still the same and the groups are still balanced, however.)
Inquiry and Nature of Science Skills in this Activity:

- Patterns and Systems
  - Patterns and Change:
    - Certain things change in some ways and stay the same in others, such as in their color, size, and weight.
    - Mathematical patterns help to predict future events and describe change in systems.
  - Systems:
    - Physical and biological systems tend to change until they reach equilibrium and remain that way unless their surroundings change.
    - No matter how substances within a closed system interact with one another, or how they combine or break apart, the total mass of the system remains the same.
    - A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.
Data/Graph Tool
Teacher’s Guide

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The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. **Be aware: do not** use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

**Generating a Graph**

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Concept: Reaction Rate

Overview: You will work with your teacher and with your classmates to make sense of written text.

Directions:

1. Before you read, create a list of new and unfamiliar words in the Explore section of “Reaction Rate.” Use the Interactive Glossary and help from your teacher to write the meanings of the glossary words.
2. Work with a partner to read the Explore section of “Reaction Rate.” As you read, use the Techbook highlighting tool to mark parts of the text that are confusing.
3. Discuss the parts that you and your partner highlighted with the whole class and with your teacher.
4. Use the Techbook note-taking tool to add helpful information that you received from your classmates and teacher.
5. Use your notes to help make sense of the text.

What parts of the Techbook are you using? ______________________________

Who are you working with?

the whole class     a group     one other person     nobody

What will you have when you finish? ____________________________________

Words to Know:

<table>
<thead>
<tr>
<th>Vocabulary word</th>
<th>Words that help</th>
<th>Picture or example</th>
</tr>
</thead>
<tbody>
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</tbody>
</table>
Hands-On Lab
Iodine Clock Reaction

Timing: one 90-minute class session

Objective(s):
Students will design a protocol to observe the classic iodine clock reaction. Students will evaluate how reaction rate is affected by temperature, reactant concentration, and catalysts.

Safety Precautions:
Students should use caution when working with the chemicals in this lab. Potassium iodate is an irritant to skin and eyes, and it can be harmful if ingested. Sodium metabisulfite is an irritant to skin, eyes, and other tissue. Sulfuric acid at this concentration is fairly corrosive to skin, eyes, and other tissue. All waste must be disposed of carefully. Students should not eat or drink anything in lab. Students should wear closed-toed shoes, eye protection, gloves, and aprons.

Materials:
For teacher demonstration:
- potassium iodate solution, KIO₃ (0.2 M), 325 mL
- sodium metabisulfite, Na₂S₂O₅, 3.8 g
- starch solution (2%), 180 mL
- sulfuric acid solution (0.1 M), 10 mL
- deionized or distilled water
- beaker, 250 mL
- beaker, 400 mL
- stirring rod
- graduated cylinder, 10 mL
- graduated cylinder, 50 mL
- graduated cylinder, 100 mL
- clock or stopwatch

Per student group:
- potassium iodate solution, KIO₃ (0.2 M), 325 mL
- sodium metabisulfite, Na₂S₂O₅, 3.8 g
- starch solution (2%), 180 mL
- sulfuric acid solution (0.1 M), 10 mL
- deionized or distilled water
- beakers, 250 mL, 6
- beakers, 400 mL, 6
- stirring rods, 6
- graduated cylinder, 10 mL
graduated cylinder, 50 mL
graduated cylinder, 100 mL
hot plate
ice bath
scale
thermometer
clock or stopwatch

Teacher Preparation:
Prepare the following solutions:
- Dissolve 3.8 g of 0.2 M sodium metabisulfite in enough of the deionized or distilled water to create a 100 mL solution. This should be used within 1-2 months.
- Mix 20 g of soluble starch (e.g., potato) with a small amount of deionized or distilled water. Add enough boiling water to create a 1 L solution. The solution should be clear when it is cooled. Use within 1-2 months.

Prepare a copy of the Student Investigation Sheet for each student.

Procedure:
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

Directed Inquiry

Model for the students the following procedure, explaining the steps as you go.
Prepare the following solution in a 400 mL beaker labeled “A1.”

<table>
<thead>
<tr>
<th>Beaker A1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 M potassium iodate solution</td>
<td>50 mL</td>
</tr>
<tr>
<td>deionized or distilled water</td>
<td>150 mL</td>
</tr>
<tr>
<td>0.1 M sulfuric acid</td>
<td>0 mL</td>
</tr>
</tbody>
</table>

Prepare the following solution in a 250-mL beaker labeled “B1.”

<table>
<thead>
<tr>
<th>Beaker B1</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.20 M sodium metabisulfite solution</td>
<td>10 mL</td>
</tr>
<tr>
<td>starch solution</td>
<td>30 mL</td>
</tr>
<tr>
<td>deionized or distilled water</td>
<td>40 mL</td>
</tr>
</tbody>
</table>
Ask students to predict what might occur if the two solutions are mixed. Have them write down their predictions in their notebook, then instruct them to be prepared to write down their observations of the reaction. Have a stopwatch ready to time the reaction.

Pour the solution from beaker B1 into beaker A1, carefully measuring the time it takes the solution to turn blue. Ask students to describe what they have seen, and whether their predictions were correct.

Ask students what they could do to change the rate of the reaction. Students should respond that the concentration and temperature of the reactants could be changed to speed up or slow down the reaction rate, or a catalyst could be added.

**Guided Inquiry**
Students can develop their own plans for collecting data, based on their knowledge of the procedure modeled above and materials available. Ask the students some guiding questions to help them focus their inquiry:

- What will be your constants?
- How will you change the temperature?
- What other variables can be changed and how will you change them?

Remind students that they should begin their activity by choosing a testable question.

*Sample questions:* If reactants are heated, will the reaction proceed more quickly? If the concentration of the reactants is increased, will the reaction proceed more quickly? If a catalyst is used, will the reaction proceed more quickly?

Point out to students that the solutions available must be handled carefully. Provide the following table and instruct them that they are to use only the solutions as described for beakers A1–A6. Have students discuss in their groups which solutions would be appropriate for testing which variables, and remind them to keep this in mind when designing their procedures. Note that Solution B and beaker A1 are controls; beakers A2 and A3 can be used to test changes in concentration; beakers A4 and A5 can be used to test changes in temperature; beaker A6 contains a catalyst. (A reproducible copy of this table appears at the end of this section.)
Concentrations to Prepare

<table>
<thead>
<tr>
<th>Solution A</th>
<th>Beaker A1</th>
<th>Beaker A2</th>
<th>Beaker A3</th>
<th>Beaker A4</th>
<th>Beaker A5</th>
<th>Beaker A6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 M potassium iodate solution</td>
<td>50 mL</td>
<td>100 mL</td>
<td>25 mL</td>
<td>50 mL</td>
<td>50 mL</td>
<td>50 mL</td>
</tr>
<tr>
<td>Deionized or distilled water</td>
<td>150 mL</td>
<td>100 mL</td>
<td>175 mL</td>
<td>150 mL</td>
<td>150 mL</td>
<td>140 mL</td>
</tr>
<tr>
<td>0.1 M sulfuric acid</td>
<td>0 mL</td>
<td>0 mL</td>
<td>0 mL</td>
<td>0 mL</td>
<td>0 mL</td>
<td>10 mL</td>
</tr>
</tbody>
</table>

Have each student pair design a procedure to answer their questions. Tell them to have their procedure approved before they begin their investigation. Remind students to define variables and create a hypothesis before they begin. Remind students to predict what they expect will occur before they change each variable. Each prediction should include a scientific explanation why. Students must also record what actually occurs, even if it matches their prediction.

Dependent variable: reaction rate
Independent variables: temperature, concentration, catalyst
Sample hypotheses: If the temperature of the reactants is increased, the reaction will proceed more quickly. If the concentration of the reactants is increased, the reaction will proceed more quickly. If a
catalyst is used, the reaction will proceed more quickly.

Sample Procedure (Concentration):
1. Prepare the solution for beakers labeled A2 and A3 as described in the table.
2. Prepare the sodium metabisulfite / starch solution as described above for two beakers labeled B2 and B3.
3. Have a stopwatch ready to time the reaction.
4. Predict what you expect to happen, and record your prediction. Explain why you expect that to happen.
5. Pour the solution from beaker B2 into beaker A2. Record the results.
6. Pour the solution from beaker B3 into beaker A3. Record the results.

Sample Procedure (Temperature):
1. Prepare the solution for beakers labeled A4 and A5 as described in the table.
2. Prepare the sodium metabisulfite - starch solution as described above for two beakers labeled B4 and B5.
3. Place beaker A4 on the hot plate until it reaches a temperature of 45°C.
4. Place beaker A5 in the ice bath until it cools to a temperature of 10°C.
5. Have a stopwatch ready to time the reaction.
6. Predict what you expect to happen, and record your prediction. Explain why.
7. Pour the solution from beaker B4 into beaker A4. Record the results.
8. Pour the solution from beaker B5 into beaker A5. Record the results.

Sample Procedure (Catalyst):
1. Prepare the solution for the beaker labeled A6 as described in the table.
2. Prepare the sodium metabisulfite - starch solution as described above for a beaker labeled B6.
3. Have a stopwatch ready to time the reaction.
4. Predict what you expect to happen, ad record your prediction. Explain why.
5. Pour the solution from beaker B6 into beaker A6. Record the results.
## Concentrations to Prepare

<table>
<thead>
<tr>
<th>Solution A</th>
<th>Beaker A1</th>
<th>Beaker A2</th>
<th>Beaker A3</th>
<th>Beaker A4</th>
<th>Beaker A5</th>
<th>Beaker A6</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 M potassium iodate solution</td>
<td>50 mL</td>
<td>100 mL</td>
<td>25 mL</td>
<td>50 mL</td>
<td>50 mL</td>
<td>50 mL</td>
</tr>
<tr>
<td>Deionized or distilled water</td>
<td>150 mL</td>
<td>100 mL</td>
<td>175 mL</td>
<td>150 mL</td>
<td>150 mL</td>
<td>140 mL</td>
</tr>
<tr>
<td>0.1 M sulfuric acid</td>
<td>0 mL</td>
<td>0 mL</td>
<td>0 mL</td>
<td>0 mL</td>
<td>0 mL</td>
<td>10 mL</td>
</tr>
</tbody>
</table>
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. What did you expect to observe in the teacher demonstration, based on your prior understanding of solutions and reaction rate? What did you actually observe? Give three examples.

I expected to see a change right away, when the two solutions were mixed. I was surprised that it took so long for the reaction to be visible. I think there are a few different reactions happening in this mixture, so maybe one happened right away and the other one was slower.

2. Give a scientific explanation for each question. Back up each explanation with an observation you made during this investigation.
   (a) How does temperature affect reaction rate, and why? Increasing temperature will increase reaction rate. The opposite is also true, so that a reaction rate decreases when the temperature drops. The explanation for this trend is that increasing temperature adds more energy to the system. In other words, all the molecules and ions are moving faster, so they are more likely to bump into each other and react. Also, if there is any threshold energy required for the reaction to start, heating the reaction will make it more likely to happen. In this investigation, when I increased the temperature of the solution by 10°C, the reaction happened 25 s faster. (Note: This is sample data only; student results will vary.)

   (b) How does concentration affect reaction rate, and why? Increasing concentration will increase reaction rate. This happens because there are more molecules and ions present, so they are more likely to bump into each other and react. In this investigation, I decreased the concentration by diluting the solution with 100 mL of distilled water. I observed that the reaction happened 10 s slower than when the solution was undiluted. (Note: This is sample data only; student results will vary.)

   (c) How do catalysts affect reaction rate, and why? Adding a catalyst increases reaction rate. When a catalyst is added, it does something to make the reaction easier. For example, a catalyst might break down the reaction step requiring the most energy into two smaller steps that don’t need as much energy to happen. In this investigation, when the catalyst, sulfuric acid, was present, the reaction happened twice as quickly as when the catalyst was not present. (Note: This is sample data only; student results will vary.)

   (d) What was the catalyst in this reaction? The catalyst was sulfuric acid.

3. Evaluate your observations for this investigation. Are they complete? Are they thorough? How might you improve your observations for your next investigation?
My observations are complete, but I think I could have included more information on what the solution looked like as the reactions took place. I could have included a sketch of my set-up apparatus.
4. Critique your explanations for Question 2 parts (a), (b), and (c), above. Did your observations match the scientific explanations? If not, why not?
Sample answer: In my explanations, I answered the question and then I gave at least one reason why. I backed up my explanations with actual observations. My observations matched the scientific explanations very well, so I think I did the investigation correctly and my explanations were correct.

5. Critique the procedure you used in this investigation. Could the procedure have been improved? If so, how? What might you do differently if you repeated this investigation?
Sample answer: The procedure worked, but it would have been better if I had spent more time on one variable instead of testing them all. Next time I could ask two friends to each test one of the other variables. I could spend all my time testing just one, and we could share our data. That way, I could test the reaction at eight or ten different temperatures and graph my results.

6. Why is this reaction referred to as an “iodine clock”?
The rate of this reaction is slow enough to see. It can be controlled very exactly by changing temperature, concentration, or using a catalyst. If the rate is set specifically, it could be used as a way to measure time—like a clock. It’s called an “iodine” clock because the reactions involve iodine.
Inquiry and Nature of Science Skills in this Lab:

- Identify Questions
  - Develop a question that:
    - asks a question about a specific science concept or process
  - Recognize and develop testable questions that:
    - Specify a cause-effect relationship
    - Require the changing of one variable at a time
    - Can be answered with a science investigation or observational study
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)
    - State the expected cause and effect (if-then statement) in an investigation based on prior knowledge and experience (hypothesis)

- Design Investigations
  - Design and conduct field studies using:
    - Interventional Study - adjusts one or more elements and observes resulting changes over time
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged in
    - Control (control group) - used for comparison in which the independent variable is not changed
    - Multiple trials - repeated tests with the same variables to check for variability of results
  - Explain the investigative processes by:
    - Describing the logical sequence that was used to conduct the investigation
    - Properly citing all equipment and materials
    - Describing it so that it can be easily repeated by a fellow scientist
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
    - Incorporating laboratory safety practices into the investigation design

- Gather Data
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
    - Temperature
    - Time
    - Speed
  - Choose appropriate tools to conduct an investigation:
    - Glassware (beakers, flasks, watch glass, etc.)
- Thermometer
- Clock/stopwatch
- Scale
- Graduated cylinder
- Other Laboratory equipment

- Use senses to observe:
  - Seeing (color, shape, size, texture, motion)
  - Touching (temperature, texture, shape, size, vibration, motion)

- Use the appropriate format to record data:
  - Table
  - Graph
  - Chart
  - Writing (journal, worksheet, electronic text)
  - Sketch
  - Diagram
  - Photograph/image
  - Audio Recording
  - Video Recording

- Interpret Data
  - Identify and interpret patterns using:
    - Analysis of data collected during an investigation

- Evaluate Evidence
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Comparing results to hypothesis
    - Answering the testable question
    - Examining how investigations can be improved
    - Formulating scientific explanations/arguments
    - Showing the application of the scientific concept or process being investigated

- Communication in Science
  - Report results using:
    - Peer presentation
    - Written report
    - Scientific illustration with proper labeling
    - Images or video
    - Audio recording
    - Scientific explanations/arguments
    - Table/graph showing data

- Analyze Scientific Results
  - Participate in critiquing/peer review by:
    - Evaluating an investigative design
    - Evaluating data for accuracy
    - Evaluating a conclusion
• Analyzing scientific explanations
  • Analyzing scientific arguments

• Patterns and Systems
  o Patterns and Change:
    ▶ Some changes are very slow and some are very fast and that some of these changes may be hard to see and/or record.
    ▶ Some small changes can be detected by taking measurements.

• Scientific Investigation
  o Scientific Investigation:
    ▶ Science investigation begins with a testable question.
    ▶ New observations should be made when there is disagreement among initial observations.
    ▶ When a scientific investigation is repeated, a similar result is expected.
    ▶ Science takes place in many locations including labs, offices, fields, and under the ocean.
    ▶ Scientific investigation results in things we know and things we don't know.
    ▶ Scientific investigations generally work the same way in different places.
    ▶ Hypotheses are valuable, even if they turn out not to be true, because they lead to further investigation.
    ▶ Scientific investigation leads to more questions.
    ▶ Different explanations can be given for the same evidence, and it is not always possible to tell which one is correct without further inquiry.
    ▶ What people expect to observe can affect how they perceive what they observe.
    ▶ Scientific investigations lead to the development of scientific explanations.
  o Scientific Data and Outcomes:
    ▶ People are more likely to believe ideas if good reasons are given for them.
    ▶ Scientific claims are based on data and reliable scientific sources.
    ▶ Collecting and analyzing data is the best way to understand a changing pattern.
    ▶ Results of similar scientific investigations may turn out differently because of inconsistencies in methods, materials, and observations.
    ▶ Comparisons of data are not accurate when some of the conditions are not kept the same.
    ▶ Accurate record keeping, openness, and replication are essential for maintaining an investigator’s credibility with other scientists and society.
    ▶ It is important in science to keep honest, clear, and accurate records.
    ▶ When similar investigations give different results, it often takes further studies to decide what is right.
    ▶ Arguments and conclusions are invalid if based on very small samples of data, biased samples, or samples for which there was no control sample.

• Scientific Endeavor
  o Characteristics of Science:
    ▶ Science is based on factual knowledge.
    ▶ Scientists are curious about wanting to know how things work.
    ▶ Scientific claims can be substantiated using data and observation.
Symbolic equations are used to show how the quantity of something changes over time or in response to changes in other quantities.

An important part of science is the critical review and analysis of any idea or conclusion.

- Engineering and Technology
  - Uses of Technology:
    - Not every problem has a technological solution.
    - Constraints, such as gravity or materials characteristics, must be taken into account as a new design is developed.
    - Even a good design may fail even though steps are taken ahead of time to reduce the likelihood of failure.
Hands-On Activity

Modeling Reaction Rates

Timing
30 minutes

Objective
Students will use diagrams to model how reactions rates change under different conditions including changes in concentration, temperature, and the use of catalysts.

Materials
Per pair:
- student worksheets
- colored pencils

Teacher Preparation
Print off the student worksheets, one per student.

Procedure:
This Hands-On Activity provides students with an opportunity to represent their understanding of what is occurring at a molecular level during chemical reactions. For this reason, it is best conducted near the end the concept and if students work by themselves, may be used as a summative performance assessment.

- Hand out the student worksheets.
- Explain the objective of the exercise. For each scenario point out the changing conditions and the purposes of the boxes on each row.
- Start with the first example and ask students how they could graphically model what is happening when the temperature of a reaction is raised. Draw or project the best ideas on the board. Spend some time sharing ideas about how to represent reactants, the kinetic energy of the particles, and the concentration of reactants and products.
- Have students complete the first scenario; Low Temperature – High Temperature. Below the diagram boxes they should write a short explanation of their representations. Students should suggest an example reaction that could be represented by each set of diagrams.
- Have students work individually or in pairs to complete the remaining scenarios.
- After about 15 minutes, bring the students back together to share their ideas for each one. Use the ensuing discussion as an opportunity to review the concept Reaction Rate.
Sample Student Responses
Student models will vary in their depiction of each scenario. Look for diagrams that distinguish between the reactants and products (and catalyst) of the reaction they are depicting, the use of arrows to depict the kinetic energy of the atoms or molecules, and changes in the concentration of products and reactants between the before and after boxes.

Diagraming Reaction Rates

Low Temperature

High Temperature

Explanation:

Low Concentration

High Concentration

Explanation:
No Catalyst Orienting Molecules

Catalyst Orienting Molecules

Explanation:

Below Activation Energy

Above Activation Energy

Explanation:
Exploration Teacher Guide: Reaction Rate

Overview

Reaction rate is a measure of the speed at which products are formed in a reaction. In this Exploration, students learn about the factors affecting the rate of a reaction.

Student Learning Objectives

- Predict the rate of reactions under different conditions.
- Analyze the factors governing reaction rate.
- Observe the rate at which products are formed by performing reactions under varying conditions.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In this Exploration, students observe the rates at which different reactions proceed under varying conditions. Students use options in the Select Reactant(s) dropdown list to choose the reaction they want to observe. The complete reaction using the selected reactants is displayed on the screen.

Next, from the radio button options displayed, students identify the reaction that will produce the products of the selected reaction at a faster rate. They use the Submit button to validate their selection. They can use the Proceed button to continue the Exploration after viewing the feedback.

Students can now analyze and compare the graphs of volume versus time, under both conditions. Students use the Simulate button to analyze the graph of the corresponding condition. They can use the Reset button to observe the varying rates of another reaction.

Using the Tracker tab, students can review the time required for each reaction, with or without altering the selected parameters.
Answers to Questions in the Student Worksheet

1. Define reaction rate.

   **Answer:** Reaction rate is defined as a measure of the speed at which a reaction proceeds. Generally, the rate of a reaction is represented as the amount of product formed per unit time.

2. List any three factors that affect the rate of a reaction.

   **Answer:** Any three of the following are possible answers: Concentration of the reactants, reactant surface area, ambient temperature, ambient pressure, and presence of a catalyst are factors that affect the rate of a reaction.

3. Describe the role of catalysts in increasing the rate of a chemical reaction.

   **Answer:** A catalyst is a substance which speeds up a reaction, but is chemically unchanged at the end of the reaction. A catalyst provides an alternative route for the reaction. That alternative route has a lower activation energy.

4. Give one example of a reaction whose rate can be increased by varying the ambient temperature.

   **Answer:** The synthesis of zinc chloride from zinc and hydrochloric acid is an example of a reaction whose rate can be increased by varying the ambient temperature. This reaction proceeds as follows:

   \[ \text{Zn}(s) + 2\text{HCl}(aq) \rightarrow \text{ZnCl}_2(aq) + \text{H}_2(g) \]

5. Explain how the concentration of reactants plays a role in determining the reaction rate.

   **Answer:** The rate of a reaction depends on the number of collisions between reactants. When the concentration of reactants is increased, the number of collisions between reactants also increases. This increases the speed with which the reaction takes place.

6. Using the Exploration, explain why powdered calcium carbonate (CaCO₃) is preferred over lumps of calcium carbonate for the synthesis of calcium chloride.

   **Answer:** When powdered reactants are used instead of larger lumps, a greater surface area of the reactants is exposed. This also increases the rate of the reaction since the action increases the amount of reactant available for the reaction.
7. Using the Exploration, determine which of the following reactions will proceed at a faster rate:

a. Synthesis of carbon dioxide from carbon monoxide and nitrogen oxide at standard pressure (1 atm).

b. Synthesis of carbon dioxide from carbon monoxide and nitrogen at a pressure of 2 atm.

**Answer:** The synthesis of carbon dioxide from carbon monoxide and nitrogen at a pressure of 2 atm will proceed at a faster rate. The number of collisions between reactants is greater under pressure. For a given mass of gas, the pressure is increased when it is squeezed into a smaller volume. If you have the same mass of gas in a smaller volume, then its concentration is higher.

8. Using the Exploration, determine if zinc and hydrogen chloride will produce zinc chloride and hydrogen at a faster rate at 100°C (212°F) or at room temperature. Determine the difference in the time to reach maximum concentration of products.

**Answer:** Zinc and hydrogen chloride will produce zinc chloride and hydrogen at a faster rate at 100°C (212°F). At this temperature, the maximum concentration of products is achieved after three seconds. At room temperature, the maximum concentration of products is achieved after five seconds.

9. Explain how the rate of a reaction can be decreased.

**Answer:** The rate of a reaction can be decreased by carrying out the reaction at a low temperature, lower concentration, lower surface area, or under low pressure. Some catalysts are also known to reduce the rate of a reaction.

10. Explain how studying the rate of chemical reactions can prove useful in industry.

**Answer:** Studying the rate of chemical reactions can be helpful in increasing the yield of chemical processes by optimizing the conditions under which the reactions are carried out.
Data/Graph Tool
Teacher’s Guide

Introduction

The skill of analyzing and communicating quantitative data is essential in science and is an expected mathematics skill. The Data Graphing Tool can be used to create a data table and then transform this data into one of a variety of graphs. This tool enables students, either individually or in groups, to carefully examine, critique, analyze, and display their data.

Data used in the tool can come from any number of sources:
- data collected by students from hands-on investigations
- data from Virtual Labs
- data from Explorations
- data from resources such as reading passages, the Internet, historical documents, reference books, and primary documents

Overview of Features

The Data/Graph Tool can be configured by the user to generate data tables with any number of columns and any number of rows. The user is prompted by the software to name the data table and identify the columns. Data can be entered in numeric, text, or formula-based format. Once a table has been created, individual columns can be toggled on or off as well as sorted from least to greatest values or vice versa. The data table can be saved, printed out, or converted into graphical form. Data can also be saved for later use.

Once a user has created a customized data table, it can be converted into one of several types of graphs: bar, line, pie, scatter, grouped bar, stacked bar, or area. After selecting a graph type, the user is guided to set up the details of the graph. The specific details will vary depending on the type of graph chosen. Once a graph has been generated, the user can zoom in on a specific area of the graph in order examine the data in closer detail.

If multiple data tables and graphs are constructed, it is easy to move back and forth between them to examine multiple sets of data. Tabs allow the user to easily move back and forth between a data table and the corresponding graph. It is also possible to view both data table and graph on the same screen.
Notes for Implementation

The following instructions are provided for you, the teacher, and, with modification, your students. How you introduce this powerful tool to your students will of course depend on your students’ skills and previous experience with data tables, data entry, data analysis, and graphing. Much like a calculator can free a student to focus on the results and significance of calculations, the Data/Graph Tool can do much the same when working with real and virtually collected data. And, like a calculator, the Data/Graph Tool can be a valuable aid to inquiry and critical thinking.

Transforming data from a table into a graph requires some planning ahead. The terms in the graph creator such as x-axis and y-axis may be new to students. The idea that there can be more than one way to display the same data in a graph may also be new to students. Therefore, you will want to take students through the steps using a think-aloud approach so they can follow the choices you make as you demonstrate them.

Once you’re comfortable with the tool, you can present it to your students in a variety of ways. Because there are a number of distinct steps to go from initially setting up a data table to examining a completed graph, it would be helpful in your presentation to be able to switch back and forth between the different steps as you demonstrate this tool to your students. One way to be able to do this is to create a new tab in your browser for each of the steps. If you do this ahead of time, you can smoothly jump to a particular step if, for example, you want to respond to a student’s question. Be aware: do not use your browser’s “previous page” (back-button) function while proceeding through the steps presented below. Any data or other entries you have made will be lost.

How to Use the Data/Graph Tool

Creating a Data Table

When you first open the Data/Graph Tool, you will be invited to create a new data table using the Table Creation Wizard by clicking on “Create Data Table.”

Note: If the computer you are using has previously been used to create a data table, a pop-up window will appear and present three options.

a) reload the most recent data from a lab since you last saved your work
b) load data from another user by typing in the ‘Save Code’
c) start a new data session

Once you choose to create a new data table, the following pop-up window will appear:
There are several elements to enter on this screen.

- Name the data table: select a descriptive title or name for the data table.
- Name each of the columns in the data table. Additional columns can be added as needed. With the drop-down menu you tell the computer if the data for a given column is to be numeric, text, or formula-based.

Further details on data types are found at the end of this guide. Columns can include variables (e.g. x and y), trial number, or any type of data element (e.g. student name).

For example, here are the inputs that would be used to set up a data table of the heights of members of the class.

Once these choices have been made, click on “Create Table” and the computer will generate a data table with the elements properly labeled.

Data can then be manually entered into the appropriate field. For each data point to be added, add a row and then type the data into the correct columns.
In this example, the height (cm) column has been selected and the heights have been ordered from least to greatest by clicking on the sorting arrows at the top of the column. This order can be reversed using the same arrows. (This feature, and others, is similar to features often found in computerized spreadsheets and was developed in part to expose students to the power and utility of spreadsheets.)

If the data table includes more than two data columns, students may find it useful to temporarily hide selected columns using the Toggle Columns link at the top of the table. Selecting the Toggle Columns link opens a pop-up window such as the one shown on the right. Students uncheck boxes to hide a column or check boxes to display a column. You might mention that they are turning the column on or off, hence the term ‘toggle.’

The ability to toggle on and off columns can facilitate students’ initial attempts to analyze their data. If, for example, students wanted to see if there were a connection between handspan and height, they could easily turn off all the columns except height and handspan and look for a connection by comparing adjacent columns.

Note that data can be printed or saved using the controls found along the top. Load Work will allow you to create a new data table using another person’s (or group’s) work if you have their Save Code.
A new data table can be created (New Table) for another set of data, if, for example, students wanted to compare heights in their class with the height of students in another class.

Generating a Graph

When you are ready to create a graph from a data table, simply click on Create Graph. The following screen will appear.

The type of data you have might determine the type of graph you select.

You will be prompted in the following screen to enter the appropriate details for the new graph. For most graphs, you will need to identify which element goes with which axis.

Note that the name of the graph (Our Class Heights) needs to be different than the name of the data table on which it was based (Our Class).
When you click Create Graph, a graph of the type you selected will be generated using the data in the data table.

Controls for viewing the data and/or the graph are along the right side of the window. The user can move between displaying the data table, the graph, or both the data table and graph in one window as seen below.
Holding the cursor over a location on the graph will display the value of that element. Only one value can be shown at a time.

Clicking on the Zoom Instructions icon near the top right of the window will reveal an option to zoom in on sections of the graph in order to view the data in closer detail.

When applied to Our Class data set, the zoom function produces the following graph.

Notice how the scaling of the y-axis has been changed and results in an exaggerated height of the values of the bars.

With practice, students will begin to understand the ways in which they can produce graphs as a picture of data that can be used to analyze and explain science phenomena.
Exploration Teacher Guide: Ocean Water

Overview

The chemical and physical properties of ocean water vary in different locations around the world. In this Exploration, students use the CTD (Conductivity, Temperature, Depth) sensor to study the characteristics of water from four of the world’s five oceans.

Student Learning Objectives

- Understand the operation of the CTD (Conductivity, Temperature, Depth) sensor.
- Determine the conductivity, temperature and pressure of different oceans at different depths.
- Analyze how ocean water conductivity, temperature, and pressure are related to depth.

Student Worksheet

The student worksheet includes questions for students to focus on. Students may review questions before going through the Exploration and can respond either during or after completion.

Using this Exploration

In the Apparatus tab, students learn about the operation of the CTD (Conductivity, Temperature, Depth) sensor and how it is used to study the characteristics of ocean water. The Setup option presents the context for the sensor’s operation in the field. The CTD Sensor option provides details about the sensor’s components and operation.

In the Explore tab, students select an ocean from the four clickable options on the world map. Available for selection are the Pacific, Southern, Atlantic, and Indian oceans. Students use the Proceed button to go to the next step of the Exploration.

In the activity area, students drag the slider to record conductivity, temperature, and pressure readings at various depths. After all readings are recorded in the table, students use the Plot button to draw the graphs of conductivity, temperature, and pressure versus depth. They analyze each graph and answer a question using the radio button options provided. Students use the Submit button to validate their answers and then use the Next button to move to the next graph. They may use the Back button to go back to the previous graph.

Students may use the Reset button to undo what they have done and record the readings again for the selected ocean. They may use the Select Another Ocean button to explore another ocean.

In the Tracker tab, students track the recorded parameters for all the oceans explored. Students use the buttons in the View Graph column, to review the graphs of the corresponding parameter versus depth, for all oceans explored.
Answers to Questions in the Student Worksheet

1. Explain how a CTD sensor samples the physical properties of the water column.

   **Answer:** A CTD sensor is attached to the frame that holds numerous niskin bottles for sampling water. This setup, often called a “rosette”, is lowered into the sea with the help of a pulley and crane on the ship. The sensor on the rosette is connected to the ship via a conducting cable that sends real-time data on the physical properties of the water column to the scientists on board. This cable also controls the opening and closing of the bottles to collect water at specific depths. Scientists conduct further chemical and biological analyses of the collected samples on board.

2. Identify the probes in a CTD sensor that measure the conductivity, temperature, and depth at a specific point in the water column.

   **Answer:** In a CTD sensor, conductivity is measured using a conductivity meter, temperature is measured using a digital thermometer, and depth is measured using a hydrostatic pressure sensor.

3. Identify the parameters that can be measured using the auxiliary sensors attached to CTD sensor.

   **Answer:** Dissolved oxygen, chlorophyll fluorescence, pH, and turbidity can be measured using auxiliary sensors attached to CTD sensor.

4. What factors determine the salinity of ocean water?

   **Answer:** Temperature, evaporation, precipitation runoff of fresh water, and depth or any combination of the above factors determine the salinity of ocean water.

5. What factors contribute to the variations of chemical and physical properties of ocean water in different locations?

   **Answer:** The factors that contribute to the variations of chemical and physical properties of ocean water in different locations are ocean physical conditions (depth, pressure, and temperature), local geographical conditions, weather conditions (temperature, precipitation, and sunlight), biotic activity, human activity, and mineral cycles.

6. Explain the relationship between pressure and density.

   **Answer:** Pressure increases with depth and is directly proportional to density. As the pressure increases with increase in depth, ocean water compresses and its density increases.
7. Describe how temperature, salinity and density of ocean water are related to each other.

**Answer:** Temperature affects salinity because the density of water varies with temperature. An increase in temperature expands water, thereby reducing its density. With lower density, the amount of dissolved minerals per unit volume decreases, lowering salinity. Conversely, when water cools, it becomes denser and the salinity of the water increases. Hence, density and salinity are directly proportional whereas temperature is inversely proportional to both.

8. Explain how precipitation and evaporation affect the salinity of ocean water.

**Answer:** When water evaporates from the ocean's surface, it leaves behind dissolved solids that raise the salinity of the remaining water. When fresh water mixes with ocean water due to precipitation, the concentration of dissolved solids is reduced, lowering salinity.

9. Use this Exploration to record and compare the temperature readings for the Arctic Ocean and for Pacific Ocean. From the temperature readings what can be inferred about the amount of solar energy in these oceans?

**Answer:** The temperatures recorded for the Arctic Ocean are lower than the ones recorded for the Pacific Ocean. This indicates that the amount of solar energy penetrating the Antarctic Ocean water is less than that of Pacific Ocean water.

**Note:** Students use the Exploration to answer this question.

10. Determine if the following statements are correct or incorrect. If incorrect, modify the statement such that it is correct.

   a. The amount of solar energy penetrating the ocean water decreases with an increase in depth.
   b. Salinity of ocean water decreases with an increase in depth.
   c. Density of ocean water increases with an increase in depth.

**Answer:**
   a. Correct.
   b. Salinity of ocean water increases with an increase in depth.
   c. Correct.
Hands-On Lab
Salinity, Density, and Temperature in Water

Timing: one 90-minute class session

Objective(s):
In this lab, students will measure and calculate the salinity of different samples of water to determine how the salinity of water affects its density and its ability to freeze. Students will also determine the effect of temperature on salinity.

Safety Precautions:
Students should take care when working with beakers and graduated cylinders; chipped glass should be reported to the teacher, and broken glass should be cleaned up immediately. Review safety procedures for working with hot plates prior to beginning the lab; students should only turn on hot plates during the appropriate section of the lab. Students should secure long hair or loose clothing before working in the lab. Students should wear eye protection, lab aprons, and closed-toed shoes and never eat or drink anything in the lab.

Materials:
Per pair:
- Metric balance
- Balance tray
- Weighing paper
- 3 paper cups (at least 100 mL each)
- Marker to label samples
- 3 beakers (at least 100 mL each)
- 3 graduated cylinders (at least 100 mL each)
- Water
- Table salt
- Stirring rod
- Hot plate
- Tongs (to hold hot beakers and remove ice from cold beakers)
- Access to freezer space
- Paper towels (to dry beakers)

Teacher Preparation:
Use deionized water if it is available to ensure that each solution contains no dissolved solids other than the salt added during the lab. If deionized water is not available, tap water may be used, but explain to students that the salinity of each solution is really higher than their calculations because of the various solids already dissolved in the tap water.
Prepare enough freezer space to hold three samples per student pair. The freezer should be set to a sufficiently low temperature so that some ice forms after 30 to 60 minutes without completely freezing the water; you will need to test this beforehand.

Prepare a copy of the Student Investigation Sheet for each student.

**Procedure:**
The Hands-On Labs include both Directed and Guided Inquiry approaches. If your students are new to the investigational methods being used in the Hands-On Lab, it is recommended that the Directed Inquiry approach be used to provide scaffolding that will ensure student safety and support the success of their investigations. Often, the Directed Inquiry approach involves modeling the basic laboratory techniques and methods to be used in the activity. A discussion of each step in the investigative process will also be included. In some cases, students may then be asked to create a procedure based on the one modeled for them. This may involve changing specific variables or adjusting the procedure to determine the effect on the outcome.

You may choose to use the Guided Inquiry path on its own or after completing the Directed Inquiry activity. During Guided Inquiry, students are allowed to conduct the investigations more independently. They will be given opportunities to formulate their own questions, develop their own procedures, and/or manipulate variables of their own choosing. It may be necessary to provide additional materials and supplies for students using Guided Inquiry. It will also be important to set clear limits on students’ activities to ensure their safety and the relevance of their inquiry experience to the content you are teaching.

**Review and Practice**
Explain that the average salinity of ocean water is 35 parts per thousand (ppt); this means there are 35 g of salt in every 1,000 mL of water. With a partner, students should calculate how to achieve this salinity in 100 mL of water. If students struggle, remind them to set up equivalent ratios, using $x$ to represent the unknown quantity (in this case, the grams of salt per 100 mL of water):

\[
\frac{35}{1,000} = \frac{x}{100 \text{ mL}}
\]

Cross-multiplying and solving for $x$ reveals that 3.5 g of salt per 100 mL of salinity are necessary to achieve a salinity of 35 ppt.

Give partners a few more problems to practice salinity calculations:
- What would be the salinity (in ppt) if we added 5 g of salt to 100 mL of water? (5 g per 100 mL; salinity = 50 ppt)
- What would be the salinity (in ppt) if we added 3 g of salt to 50 mL of water? (3 g per 50 mL = 6 g per 100 mL; salinity = 60 ppt)
Review these problems as a class to make sure that all students are comfortable calculating salinity in ppt; then, explain that students will be creating solutions with different salinities:

- The salinity of one solution will equal that of ocean water
- The salinity of another solution will be 100 ppt, or greater than that of ocean water.

Students will also examine the effect of freezing these solutions on salinity. This will require students to know the density of each solution. Review the density formula with the class (density equals mass per unit volume); students will know the volume of each solution (100 mL), but how will they determine the mass?

To review this process, instruct each pair to use the metric balance, cups, and beakers or graduated cylinder to determine the mass of 100 mL of water. Each pair should do this twice, once per partner, to ensure that each partner obtains the same measurement. (Students should first use the balance to measure and record the mass of the empty cup. Next, they should use the beaker or graduated cylinder to measure 100 mL of water and pour the water into the cup. Next, they should use the balance to measure and record the mass of the cup with the water in it. Finally, they should subtract the mass of the empty cup from the combined mass of the cup and water; the difference is the mass of the water.)

Review each pair’s measurement as a class to make sure that every student has measured the mass of 100 mL of water correctly.

**Directed Inquiry**

Begin by asking partners to brainstorm answers to the following guiding question:

- What would you need to know to calculate the new density of the water once it is frozen?

Possible answers include:

- Ice will need to be removed.
- The density of the water is known.
- Taking the mass and volume should result in an increased density.

Distribute the materials to each pair of students. Each set of partners should follow the procedure below and record their measurements in the data tables that follow:

**Part I**

1. Label the three paper cups as follows: Fresh water; Seawater; 10 g salt. (Partners should also label each cup with their initials to distinguish them from other sets of cups.)
2. Measure 100 mL of water in each beaker. Record the mass of 100 mL of water in the data table. Pour one of the beakers into the cup labeled “Fresh Water.”
3. Using the balance and weighing paper, measure 3.5 g of salt. Add it to the second beaker, and stir with the stirring rod until the salt has dissolved completely. The addition of the salt will have
slightly increased the volume, so use the graduated cylinder to measure exactly 100 mL of this solution, and pour it into the cup labeled “Seawater.”

4. Using the balance and weighing paper, measure 10 g of salt. Add it to the third beaker, and stir with the stirring rod until the salt has dissolved completely. The addition of the salt will have slightly increased the volume, so use a clean graduated cylinder to measure exactly 100 mL of this solution, and pour it into the cup labeled “10 g salt.”

5. Record the mass of each solution in the data table.

6. Calculate the density (in g/mL) and salinity (in ppt) of the water in each of the cups, and record these data in the table.

7. Place the three labeled cups in the freezer for 30 to 60 minutes. Have students hypothesize: What will happen to the salinity and density of the samples as they freeze? Which sample will experience the greatest change in salinity or density? Students should record their hypotheses in their notes to reference later. Partners should also rinse and dry their beakers and graduated cylinders thoroughly to reuse in Part II.

Part II

8. As the samples freeze, have students hypothesize: Will warmer water hold more or less dissolved salt than cooler water? Working with their partners, students will test their hypotheses in this part of the lab.

9. Measure 100 mL of fresh water in two beakers. Record the mass of each beaker filled with fresh water in the data table.

10. Slowly add salt to the water in one beaker while stirring. Make sure that all salt is dissolved before adding more. When no more salt will dissolve, record the mass of the beaker filled with saltwater in the data table. Use this measurement plus the mass of the beaker and fresh water to calculate the mass of the added salt.

11. Heat the second beaker on the hot plate for five minutes at high heat; if water starts to boil before five minutes pass, remove the beaker from the hot plate to prevent water from boiling away. After five minutes, remove the beaker and begin adding salt to the heated water. Continue adding salt slowly until no more salt will dissolve. When no more salt will dissolve, record the mass of the beaker filled with heated saltwater in the data table. Use this measurement plus the mass of the beaker and fresh water to calculate the mass of the added salt.

12. Calculate the salinity of the two samples. Students should use their data to determine whether their hypotheses are correct: Did warmer water hold more or less dissolved salt than cooler water?

13. Partners should rinse and dry their beakers and graduated cylinders thoroughly to reuse in Part III.

Part III

14. Partners should remove their samples from the freezer after enough time has passed for some ice to form in each cup without the water freezing completely (about 30–60 minutes). Students
should compare the ice that has formed in each container, recording their observations in their notes, and then use tongs to remove the ice from each cup without removing any water.

15. Measure and record the mass of each sample minus the ice. Then, empty each sample into a graduated cylinder to measure and record the volume of the remaining water.

16. Calculate the new density and salinity of each water sample. Students should use their data to determine whether their hypotheses are correct: Which sample experienced the greatest changes in salinity and density, and how did each sample’s salinity affect these changes?

17. Compare data with other nearby groups, and discuss the results as a class.

Guided Inquiry
Students can develop their own plans for collecting data, based on their knowledge of the procedure and materials used. Ask the students some guiding questions to help them focus their inquiry:

- What data are necessary to find the density and salinity of each sample?
- What will happen to the salinity and density of each sample as it freezes? Which sample will experience the greatest change in salinity or density?
- Will warmer water hold more or less dissolved salt than cooler water?

Students may also choose to modify the procedure for Directed Inquiry by changing different variables. For example:

- Dissolving different amounts of salt in each sample.
- Heating the solutions to different temperatures (will require a thermometer) or for different lengths of time.
- Comparing the amount of salts that may be dissolved in equal volumes of deionized water and tap water.
### Sample Data Tables:

<table>
<thead>
<tr>
<th>Empty masses (g)</th>
<th>Paper cup</th>
<th>Beaker</th>
<th>Graduated cylinder</th>
</tr>
</thead>
</table>

### Salinity and Freezing:

<table>
<thead>
<tr>
<th>Sample:</th>
<th>Water</th>
<th>Seawater</th>
<th>10 g salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of water and cup (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of water (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mass of water and salt (g)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density of water (g/mL)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity of water (ppt)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### After Freezing:

| Volume of water (mL) | | |
| Mass of water (g) | | |
| Density of water (g/mL) | | |
| Salinity of water (ppt) | | |

### Heating and Salinity:

<table>
<thead>
<tr>
<th>Sample:</th>
<th>Water</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of water in beaker</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Analysis and Conclusions:
In order to help students analyze and interpret their results, consider discussing some or all of the following questions, or assigning them as homework:

1. How did the actual results compare with your hypotheses? Answers will vary.

2. Why did the water’s salinity change as the water froze? A decrease in water volume caused an increase in salinity because the samples contained the same amount of salt but lower volumes of water.

3. Did the water’s density change as the water froze? If so, why? Yes. The water’s density changed as the water froze. The water’s volume decreased, but the amount of salt remained the same. So there was more mass for a lower volume, resulting in increased density.

4. Are these density changes and salinity changes seen in the oceans? If yes, then where? Density differences drive the deep-ocean currents.

5. How is this system different from the deep-ocean current system? Share your conclusions with your partner and critique each other’s reasoning. Do you agree or disagree? Answers will vary. The deep-ocean currents are driven by density changes as the water cools, rather than by changes in salinity. Cooler water is denser. My partner and I both basically agree, but my partner also pointed out that additional factors such as chemical variations would play more of a role in deep-ocean currents.
Inquiry and Nature of Science Skills in this Lab:

- **Identify Questions**
  - Develop predictions/hypotheses that:
    - State what may happen in an investigation based on prior knowledge or experience (prediction)

- **Design Investigations**
  - Make or use models that:
    - Simulate a real thing that cannot easily be studied or manipulated.
    - Apply mathematical operations and principles to replicate the real thing.
  - Practice lab safety by:
    - Following lab safety procedures
    - Recognizing safety equipment and materials and knowing their proper use
  - Design and conduct investigations using:
    - Fair test - changing only one variable at a time makes comparisons valid
    - Independent variable - the one variable the investigator chooses to change
    - Dependent variables - what changes as a result of, or in response to, the change in the independent variable
    - Constant - identify variables that must remain unchanged

- **Gather Data**
  - Use tools and the SI (metric) system to accurately measure:
    - Volume
    - Mass
  - Choose appropriate tools to conduct an investigation:
    - Balance
    - Graduated cylinder
    - Hot plates
    - Beakers
  - Use the appropriate format to record data:
    - Table

- **Interpret Data**
  - Identify and interpret patterns using:
    - Trends in data
    - Analysis of data collected during an investigation

- **Evaluate Evidence**
  - Draw and support a conclusion by:
    - Using data to determine the cause-effect relationship observed in the investigation
    - Comparing results with hypothesis
    - Extrapolating results beyond the investigation

- **Patterns and Systems**
  - Systems:
- No matter how substances within a closed system interact with one another, or how they combine and break apart, the total mass of the system remains the same.
- A system usually has some properties that are different from those of its parts but appear because of the interaction of those parts.