Welcome to the You Be The Chemist Challenge®!

Welcome to the You Be The Chemist Challenge! The Challenge is an exciting academic competition that will expand your knowledge of the science of chemistry and beyond.

These study materials expose you to the fascinating world of chemistry as it applies to your everyday life. It shows you how chemicals shape your world and helps you further your understanding of chemistry. Challenge questions are largely derived from information contained in CEF’s study materials but are not limited solely to this information. We encourage you to seek additional examples and explanations of chemistry concepts. Doing so will help you answer questions that require you to connect concepts and apply your knowledge of chemistry to both familiar and unfamiliar situations.

How do I use these study materials?

The information in the Passport to Science Exploration study materials is meant to help you succeed at every level of the Challenge. The Passport is divided into three portions that each correspond to a level of the Challenge—The Core of Chemistry (local), Chemistry Connections (state), and Chemistry Concepts in Action (national).

This portion, The Core of Chemistry, provides you with a strong foundation for understanding chemistry. You need to be familiar with this information for Local Challenge competitions1, as well as for State and National Challenges. We also encourage you to explore all of the study materials provided on CEF’s website, www.chemed.org, as well as outside resources. The more you explore, the more likely you are to find answers to the questions you have about the world around you!

If you are not sure about how to prepare for a particular level of competition, ask your teacher or Local Challenge Organizer. You may also contact the Chemical Educational Foundation® (CEF) at challenge@chemed.org.

The following tips will help you get the most out of the information provided.

1. Read over the Table of Contents first. These pages introduce you to the concepts covered.

2. Review the Objectives list provided at the beginning of each section to become familiar with the topics you will learn. Once you have completed your study of the entire section, go back and review the Objectives again. Can you complete the tasks listed in the Objectives? If not, review the section again.

3. Focus on the definitions of the bolded terms.

4. Use the diagrams, pictures, and illustrations to gain a better understanding of the concepts.

5. Read through material in the circles labeled “Quick Fact.” Quick Facts give further details and provide applications to help you understand the material even better.

6. Read the information in the History boxes. These boxes provide a variety of background knowledge about chemistry concepts and help to connect science of the past to science today.

1The categories of CEF study materials and/or specific concepts covered in Challenge competitions may be adjusted at the discretion of CEF or of Challenge Organizers (with the approval of CEF). Students will be notified by their Local Challenge Organizer in the event of such changes.
7. Use the information in the Element boxes to learn more about specific elements within a section.

8. Read through the questions in the “Think About It” sections. The answers to some questions may be obvious after reading the material, some may not even be known to scientists. These questions are meant to make you think! Use them to learn more about chemistry and find out what questions scientists have or have not been able to answer. (Search the Internet, check chemistry books, or ask a scientist or teacher to find an answer.)

Once you are finished with a section, do a quick review to make sure you learned all the concepts introduced in that section. If you find that you still do not understand something, pull out a science textbook and look in the index for the information or conduct a search on the Internet (be sure to find a reliable source). If the explanation you find is unclear, ask your science teacher for help.
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SECTION I: SCIENCE—A WAY OF THINKING

OBJECTIVES
- Identify key components of scientific inquiry and the scientific method.
- Distinguish between different types of variables in a scientific experiment.
- Distinguish between theories and laws.

WHAT IS SCIENCE?
Science is a systematic way of learning about the world by collecting information. It is a way of thinking that helps people gain knowledge about the world. You have probably thought like a scientist to solve problems and answer questions. You have probably began with a thought like "I wonder why this happens." People are curious by nature, so science helps us find answers to questions or learn more about something.

SCIENTIFIC INQUIRY
Scientific inquiry refers to the different ways that scientists explore the world. It is the way scientists have come to understand so much and how they can continue to learn. The scientific method is a traditional model of how to conduct scientific inquiry. It guides scientists as they ask and answer questions about the world. There are many ways to explore science, so different books, websites, and documents describe the scientific method in different ways. No matter how it is presented or in what order it occurs, the scientific method uses these basic concepts along the way: observation, research, hypothesis, experiment, data collection & analysis, conclusion, and communication of ideas and results.

OBSERVATION
Scientific inquiry usually begins with an observation. Scientists explore and collect information with their senses (smell, sight, sound, touch, and taste) and ask questions that they would like to answer. Questions can guide scientists in their research and can usually be answered by collecting evidence.

Quick Fact
Scientist Carl Sagan once said, “Science is a way of thinking much more than it is a body of facts.”

Quick Fact
Keep in mind, scientific inquiry does not need to go step by step. Actually, it often doesn’t work that way. Scientists observe, ask questions, and conduct research throughout the process. They also ask and write down new questions while collecting data and forming conclusions.
EXAMPLE:

**Observation:** You pour hot water into an ice cube tray and place the tray in the freezer. When you check the freezer a bit later, you notice the hot water seemed to form ice cubes faster than you expected.

**Question:** I wonder if hot water and cold water freeze at different rates. Will one take longer than the other?

RESEARCH

After asking a question based on their observations, scientists do research. Many scientists and students spend time reading papers and books on past research before beginning their own experiments. Often times they will find that other scientists have conducted experiments that try to answer a similar question. Conducting research helps scientists better understand their observations and questions before they begin their experiments.

If you are doing research, you want to make sure the information you’re reviewing or learning is from a credible source. *Credible* means the information or the source of the information is believable and trustworthy.

EXAMPLE:

Your friend writes a paper on why he/she thinks the dinosaurs went extinct without doing any studies or research. On the other hand, a team of 10 scientists studied the earth and the bones of dinosaurs for years. Then, they wrote a paper on their findings, and that paper was reviewed critically by another team of scientists. Their paper gives a different reason for the dinosaurs’ extinction. Whose information would you be more likely to trust? The paper written by the team of scientists is considered to be more credible.

As you do research, you should also be careful to look for gaps or errors in prior research. Sometimes there is more than one explanation for why something happens. If you only test for one of those factors, you will only get a partial answer.

EXAMPLE:

A group of scientists conducts research on whether 5th grade students learn better when they work in groups or when they work individually. They find that the students learn better when they work individually. When you review their research, you notice that they conducted their experiment at an all boys school. Is there something missing? Would the answer be different if girls were included in the experiment? This doesn’t mean their experiment was bad. Instead, it gives you important information. It also may lead other scientists to conduct new experiments. For example, another scientist might ask: Do young boys and young girls learn differently?
HYPOTHESIS
With a question in mind, scientists decide on what they want to test (they may have changed their original question after conducting some research). Scientists state clearly what they plan to test during their experiment. This statement is called a hypothesis, which is a possible answer to a scientific question or an explanation of an observation. Many people refer to this as an educated guess that may explain the observation. A hypothesis guides the experiment.

EXAMPLE:

**Hypothesis:** If containers of hot and cold liquid water are put in a freezer, the container with hot water will freeze (form ice cubes) faster.

A scientific hypothesis must be testable. The hypothesis above is inexpensive and interesting to test! You can conduct an experiment to measure the time it takes for ice cubes to form, starting with water at different temperatures.

EXPERIMENT
After making a hypothesis, scientists design and conduct an experiment. Scientists must be sure to design the experiment so that only one factor is tested at a time (you will see this in the next section on Designing an Experiment). This way, scientists will know that their results are directly related to the one thing that was changed. If the experiment is not designed carefully, the results may be confusing and may not help answer the hypothesis. Designing an experiment can be tricky and may take several tries to get it right.

EXAMPLE:

You are going to test your hypothesis about the effect of temperature on the rate at which ice cubes form. You should figure out when you should put the water in the freezer. (How soon after you measure the temperature should the water go in the freezer?) Be careful to use the same amount of water each time. You should also be sure to use the same type of water. (If you use tap water for the hot water test, then use tap water for the cold water test. Don’t switch from tap water to salt water.) These are only some of the things you need to consider.

DATA COLLECTION & ANALYSIS
Data are pieces of information collected before, during, and after an experiment. It is important to keep detailed notes and record all data during an experiment. Scientists can then analyze their data after completing the experiment to determine the results. To analyze data means to examine it carefully and critically. Sometimes data makes more sense in a graph or as a picture. Scientists may choose to record data on a table and then put the information into a graph.
Scientists have to make sure that they collect accurate data so that they can trust their results. They may also repeat an experiment to see if they can obtain the same results each time.

**EXAMPLE:**

You measure the temperature of one cup of water. It has a starting temperature of 25 °C. You record this temperature in your notebook. You measure the temperature of another cup of water. It has a starting temperature of 55 °C. You record this temperature in your notebook. You might test other temperatures as well, such as 35 °C and 45 °C. As you conduct your experiment, you will also write down how long it takes each cup of water to freeze and any other observations that you make during your experiment. Then, you can show the results in a graph that illustrates the freezing time in relation to the starting temperature. You should also repeat the experiment to make sure that your results can be reproduced and that you can trust your data.

**CONCLUSION**

If the hypothesis was testable and the experiment gives clear data, a conclusion can be made based on data. A conclusion is a statement that tells whether or not your hypothesis was correct. The conclusion is always backed up by data. Scientists rely heavily on their data so they can make an accurate conclusion.

- If the data support the hypothesis, then the hypothesis is considered correct or *valid*.
- If the data do not support the hypothesis, then the hypothesis is considered incorrect or *invalid*.

Scientists learn something from both valid and invalid hypotheses. A new hypothesis can be made or adjusted if they want to test something else, but both valid and invalid hypotheses lead to scientific learning!

**EXAMPLE:**

Based on your data, you can say whether or not hot water freezes faster than cold water. If your data show that hot water freezes faster than cold water, your hypothesis is valid. If your data show that cold water freezes faster than hot water, your hypothesis is invalid. Even if your hypothesis is invalid, you can still form a conclusion based on your data.

**COMMUNICATION**

Scientists want to tell others what they have learned. Scientists will often report their findings in journals or speeches. They may create diagrams or other images to show their results. Communication is very important! It gives other people a chance to learn more. It also allows scientists to improve their own experiments because other people may comment on the results.

**EXAMPLE:**

You make a poster for the school science fair that explains your experiment and shows your results. People will look at it, ask questions, and possibly make suggestions. They will be able to learn from what you did. They may also want to know what you plan to do with this information. Will this information change the way you make ice?
**DESIGNING AN EXPERIMENT**

Scientists need to figure out a plan for testing a hypothesis. To do this, they need to design an experiment. Scientists have to be careful to measure only one thing at a time so that they know that the results are related to the one thing that was changed. If an experiment tests more than one factor at the same time, scientists may not be able to learn anything. When designing an experiment, scientists must also identify the variables and controls.

**EXAMPLE:**

A student wants to test the hypothesis about water temperature and freezing rates. To do this, the student must keep everything else in the experiment the same. If the student places the water cups in different areas of the freezer, one may freeze faster simply because its spot in the freezer is colder. Without keeping other aspects of the experiment the same, the student will not be able to find an accurate answer.

**VARIABLES**

Factors that change in an experiment are known as **variables**:

- **Independent variable**: the variable you are going to change in the experiment. This may also be called the manipulated variable.
- **Dependent variable**: the variable you observe when the independent variable is changed. This may also be called the responding variable.

In an experiment, scientists can see how changes to the independent variable affect the dependent variable.

**EXAMPLE:**

A student wants to know if water at different temperatures will freeze at different rates. The independent variable is the water temperature, because hot and cold water will be tested. The dependent variable is time, because the amount of time it takes for ice to form depends on whether it is hot water or cold water.

**EXAMPLE:**

A student wants to explore how changing the temperature of a gas changes how much space it occupies. The student will measure the new volume of the gas each time the temperature is changed. The temperature is the independent variable. The volume is the dependent variable.
Data collected during an experiment relates to variables and can sometimes be plotted on a graph. The independent variable is plotted on the x-axis (horizontal axis). The dependent variable is plotted on the y-axis (vertical axis). The graph below shows the relationship between the temperature and volume of a gas.

**RELATIONSHIP BETWEEN THE TEMPERATURE & VOLUME OF A GAS**

![Graph showing the relationship between temperature and volume of a gas.](image)

Graphing your results can also help you better understand the experiment. You can see in the graph above that as the student increased the temperature of the gas (independent variable), the volume of the gas (dependent variable) also increased.

**CONTROLS**

A controlled experiment is an experiment in which all conditions except one are held constant. Controlled experiments help explain why you got the results that you did because only one thing was changed at a time.

Often an experiment may have two or more different setups. An experimental setup is one arrangement of materials in the overall experimental design. If nothing is changed in one of those setups, it is called the control group (also known as the control). The control group helps you to know what happens when you don’t make any changes (when the setup is left alone). In the other setups, the independent variable is changed. After your experiment, you can compare the data from the different setups.

**EXAMPLE:**

Different types of paint are used on the outside of three identical boxes. A student wants to know what type of paint will cause the inside of the box to heat up the fastest when the box is placed in the sun.

One setup is a box with a water-based paint on the outside. Another setup is a box with an oil-based paint. A third setup is a box with no paint. **The control group in this experiment would be the box with no paint on the outside.** After the experiment, the student would compare the results from the control box (control group) to the results of the painted boxes (experimental group).
**Controlled variables** (also sometimes known as constants) are things that should not change during an experiment. Experiments often have many controlled variables and are used to make sure that your comparisons are meaningful.

**EXAMPLE:**

In the previous example, a controlled variable would be the type of box used in the experiment. All the boxes should be made of the same material. What if one box was made of wood and another box was made of metal? Then, the type of box would not be controlled. As a result, the experiment would be testing both the type of box and the type of paint on the box.

Another controlled variable would be the size of the box. All the boxes should also be the same size. If one box was large and another was small, that may have affected your results.

**THEORIES AND LAWS**

Even after scientists make a conclusion and communicate it to others, their work is still not done. Scientists can conduct similar experiments to collect more data. Experimenting helps scientists understand their original observations. However, answering one question usually leads to more questions. At this point, scientists can design new experiments to explain why something happened or to answer some other related question. They will collect new data with each experiment. They can then combine and compare all of that data. Sometimes the information can be used to develop a theory or a law.

**THEORY:** an explanation of some event or phenomenon that is well supported by data. Theories have the following things in common:

- Theories are not facts. They may change as more information becomes available.
- The best known theories have been tested over and over, producing the same results.
- Theories attempt to explain “why” something occurs. They can be used to predict the results of future observations.
- Examples of theories include the Theory of Relativity, the Kinetic Molecular Theory, and the Theory of Evolution.

**LAW:** a description of a natural event or phenomenon shown to occur again and again under the same conditions. Scientific laws describe the observed pattern without trying to explain it.

- Laws are usually accepted as true and universal. They are well supported by observations, experimentation, and data.
- Still, scientific laws can be challenged and possibly disproven. However, disproving a scientific law is very rare. (It is more likely that a law will become part of a broader theory or law.)
- Laws generally state that a particular event or thing will always occur if certain conditions are met.
- Many scientific laws can predict things and events so well that they use math. They can be expressed as an equation.
OBJECTIVES

• Demonstrate the differences between accuracy and precision.
• Identify common physical properties.
• Explain the difference between mass and weight.
• Work with metric prefixes.
• Perform simple conversions between metric units.
• Write large and small numbers in scientific notation.

Scientists use many skills as they investigate the world around them. They make observations by gathering information with their senses. Some observations are simple, like figuring out the color or texture of an object. However, if scientists want to know more about a substance, they may need to take measurements. Measurements provide scientists with a quantity. A quantity describes how much of something there is or how many of something there are. For example, if scientists want to know how long an object is, they will take a measurement and get a specific quantity that describes the length of the object. Measurements require tools, such as a ruler to figure out an object’s length.

CERTAINTY IN MEASUREMENT

Scientists can use accuracy and precision to describe their measurements.

• Accuracy: refers to how close a measured value is to the true measurement (true value) of something.

• Precision: refers to the ability to take the same measurement and get the same result over and over.

EXAMPLE:

A team of scientists from the National Institute for Standards and Technology (NIST) measures a baseball that was used to set a major league home run record. They determine that its mass is 146 grams. The NIST scientists write a report stating that they think 146 grams is an accurate value. The NIST team uses good equipment. They also measure the ball a few times, getting the same result each time. Therefore, the value of 146 grams is accepted by the scientific (and baseball!) community as accurate.
EXAMPLE:
The famous baseball is part of a Major League Baseball exhibit. The exhibit travels to different areas across the country. While in Arizona, a professor at a local university is given permission to measure the ball’s mass. She measures its mass three times. She records the following—144 grams, 144 grams, and 144 grams. Her measurement was the same each time. Therefore, her measurements have high precision. However, the accepted mass is 146 grams so her measurements of the mass of the baseball are not considered accurate.

TYPES OF PHYSICAL MEASUREMENTS
Scientists take many different types of measurements depending on what they wish to learn.

MASS: a measure of the quantity (or amount) of material in a substance. (You can think of it as the amount of “stuff” in a substance.)

- Mass is usually measured with a balance or balance scale (see the Laboratory Equipment section).
- To determine the mass of an object, the object is compared to another object with a mass that is known.
- The unit of measure that scientists use to measure mass is the kilogram (kg) or gram (g).

WEIGHT: a measure of the pull of gravity between an object and the earth (or the planets, sun, etc.). Therefore, weight is actually a measure of force.

- Weight is usually measured on a weighing scale or spring scale.
- The unit of measure that scientists use to measure weight is the Newton (N). It is the same unit that is used to measure force.
- In the U.S. customary units system, people often measure weight in pounds (lbs).

Think About It...
The university professor may not have the reputation that NIST does. However, the difference between the measurements (144 g and 146 g) is large. What could be the reason? Have they checked their measurement equipment? Could the atmosphere or humidity in the different locations make a difference? These questions could lead to a hypothesis and a new experiment!

Quick Fact
Another way to measure mass is to see how hard it is to change the object’s velocity (speed). Think about pushing a baby in a stroller. You will have to push with a certain force to move the stroller forward at a walking speed. Then, think about what would happen if you put the baby’s twin brother in the stroller, too. You will have to push almost twice as hard to get up to the same speed in the same amount of time. If you increase the mass of the object, the force needed to change the object’s velocity will increase.
• Weight is not the same as mass but the two measurements are related. Two pennies have twice as much mass as one and twice as much weight too!

• The strength of gravity’s pull on an object depends on distance and mass. As mass changes, weight changes. As the distance between the objects changes, weight changes.
  – Mass is proportional to weight. Proportional means that they change at a constant rate.

Quick Fact
Mass vs. Weight:
Most of us know how much our body weighs. Now, we have learned that this measure is different from our body’s mass. The gravity on the earth gives us a certain weight. Other places, like the surface of the moon, have a different gravitational force. A person’s weight on the moon is much lower (one-sixth of his/her weight on the earth) because the moon has a lower gravitational force. However, a person’s mass does not depend on gravity. Therefore, mass doesn’t change with location. It is the same on the earth and on the moon.

WEIGHT ON OTHER PLANETS
The table below shows approximately what a person who weighs 100 pounds (and has a mass of 45.4 kg) on the earth would weigh on other planets:

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mercury</th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
<th>Jupiter</th>
<th>Saturn</th>
<th>Uranus</th>
<th>Neptune</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (in pounds)</td>
<td>38</td>
<td>88</td>
<td>100</td>
<td>38</td>
<td>235</td>
<td>105</td>
<td>89</td>
<td>120</td>
</tr>
</tbody>
</table>

LENGTH: a measure of how long an object is or the distance an object spans.

• Length may be measured using a meter stick, ruler, or tape measure. Depending on the object, scientists may need to use other more complicated instruments.

• Scientists use the meter (m) as the standard unit for measuring length.

VOLUME: the amount of space that matter occupies. (Think of it as the amount of space that an object or substance takes up.)

• Scientists measure volume in units of liters (L) or cubic centimeters (cm³ or cc). One cubic centimeter is equal to one milliliter (mL).

• Volume can be measured in different ways (see the Laboratory Equipment section).
  – To find the volume of a liquid, you can simply pour the liquid into a graduated cylinder.
  – To determine the volume of a rectangular solid, follow the steps below:
    1. Measure the length of the solid. Write down your measurement.
    2. Measure the width of the solid. Write down your measurement.
    3. Measure the height of the solid. Write down your measurement.
    4. Multiply your three measurements together. This number is the volume of the solid.

  \[
  \text{Volume (V)} = \text{length (l)} \times \text{width (w)} \times \text{height (h)} \\
  V = l \times w \times h
  \]
EXAMPLE:

Look at the box below. The length, width, and height are each 1 cm. If you multiply these numbers \((1 \text{ cm} \times 1 \text{ cm} \times 1 \text{ cm})\), you get a volume measurement of \(1 \text{ cm}^3\).

\[
V = l \times w \times h \\
V = 1 \text{ cm} \times 1 \text{ cm} \times 1 \text{ cm} \\
V = 1 \text{ cm}^3
\]

Likewise, if you have a box that has a length of 2 cm, a width of 1 cm, and a height of 4 cm, what is its volume?

\[
V = l \times w \times h \\
V = 2 \text{ cm} \times 1 \text{ cm} \times 4 \text{ cm} \\
V = 8 \text{ cm}^3
\]

TEMPERATURE: a measure of the average kinetic energy (energy of motion) of particles of matter. A simple way to think of it is as a measure of how fast the particles are moving around in matter. A higher temperature means that there is more energy, so particles are able to move at faster rates.

- Any device that measures temperature is called a thermometer.
- Scientists generally measure temperature in degrees Celsius \((^\circ\text{C})\) or Kelvin \((\text{K})\).
- The Kelvin temperature scale is actually a shifted Celsius scale that includes absolute zero \((0 \text{ K})\). If you want to convert a Celsius temperature into Kelvin, you just add the number 273.15 to the Celsius temperature.

  - A normal room temperature is considered to be about \(25 ^\circ\text{C}\). That temperature in Kelvins is about 298 K.
    (Here’s how you get that answer: \(25 ^\circ\text{C} + 273.15 = 298.15 \text{ K}\))

- Fahrenheit is the temperature scale commonly used in the United States. Degrees Fahrenheit can also be calculated from degrees Celsius using a conversion formula.

FORMULAS:

- \([\text{K}] = [\text{°C}] + 273.15\) \(\text{K} = \text{Kelvin: the metric scale for absolute temperature}\)
- \([\text{°F}] = (1.8 \times [\text{°C}]) + 32\) \(\text{°F} = \text{degrees Fahrenheit: scale generally used in the United States}\)
- \([\text{°C}] = \frac{[\text{°F}] - 32}{1.8}\) \(\text{°C} = \text{degrees Celsius: the metric scale for temperature}\)

Quick Fact

One thousand cubic centimeters \((\text{cm}^3)\) equals one liter \((\text{L})\).

\(1,000 \text{ cm}^3 = 1 \text{ L}\)

Quick Fact

When you multiply measurements together, their units are also multiplied. Volume has the units of \(\text{cm}^3\) because the length, width, and height use centimeters:

\(\text{cm} \times \text{cm} \times \text{cm} = \text{cm}^3\)

Quick Fact

Most people think of temperature as a measurement of hot and cold. To scientists, temperature measures the kinetic energy of molecules in a material. Molecules with high kinetic energy have high temperatures. They are said to be hot. Molecules with low kinetic energy have low temperatures and are said to be cold.
**Density**: the amount of matter per unit of volume. An object that is very dense has a lot of stuff crammed into a small amount of space.

- Density gives the relationship between two measurements: mass and volume. A higher density means that there is more mass in a smaller amount of space.

\[
\text{Density (D)} = \frac{\text{mass (m)}}{\text{volume (v)}} \quad \text{or} \quad D = \frac{m}{v}
\]

- To calculate density, you must find the mass and volume of the substance. Scientists usually use kilograms per cubic meter (kg/m³), grams per milliliter (g/mL), or grams per cubic centimeter (g/cm³ or g/cc) depending on what substances they are working with.

**Example:**

Gold has a density of 19.3 g/cc at 20 °C. Therefore, 19.3 grams of gold take up 1 cubic centimeter. Likewise, 1 cubic centimeter of gold has a mass of 19.3 grams.

On the other hand, water has a density of only about 1 g/mL at 4 °C. Therefore, 1 milliliter of water has a mass of 1 gram. (At 20 °C, the density of water is 0.998 g/mL.)

Air has an even lower density. The density of air at 20 °C is only 0.0013 g/cc.

- How you measure density will depend on the type of substance you are measuring. To measure the density of a liquid, you can follow the steps below:

1. Place an empty graduated cylinder on a balance (see the Laboratory Equipment section). Write down your measurement. Then, remove the graduated cylinder from the balance. You don’t want to spill any liquid on your balance.
2. Pour some of your liquid into the graduated cylinder. Write down the volume of the liquid. Remember to take your measurement from the meniscus (see the Laboratory Equipment section).
3. Place the graduated cylinder with the liquid inside on the balance. Write down your new measurement.
4. Determine the mass of the liquid. You can do this by subtracting the mass of the empty graduated cylinder from the mass of the graduated cylinder and liquid together.
5. Plug your measurements of mass and volume into the density equation to calculate the liquid’s density.

**Think About It...**

Are 100 grams of potatoes and 100 grams of marshmallows the same size? They have the same mass, but the potatoes will take up much less space than the marshmallows. So, do they have different densities? If so, which has the greater density?

**Quick Fact**

Density changes with temperature and is often reported with the temperature at which it was measured. For example, at 4 °C, pure water has a density of 1.0 g/mL.

In general, when temperature increases, the atoms in a substance move farther apart, and the substance becomes less dense. When temperature decreases, the substance becomes denser. Water, however, is an exception. The density of an ice cube at 0 °C is 0.917 g/mL.
• To measure the density of a solid, you can do the following:
  
  1. Place your solid on a balance. Write down its mass.
  2. Measure the volume of the solid. If it is a rectangular solid, you can use the calculation on page 14. If the solid has an irregular shape, you will need to use a displacement method (see the Laboratory Equipment section). Write down your measurement.
  3. Plug your measurements of mass and volume into the density equation to calculate the solid’s density.

**PRESSURE:** the amount of force exerted on an area. **Force** is the amount of push or pull on an object.

\[
p = \frac{F}{A}
\]

• Many forces affect people and objects on the earth. These forces include gravity and magnetism.

• Force and pressure are related, but they are not the same thing.

• Pressure is usually measured with a barometer or a manometer.

• Scientists commonly use the following units to measure pressure: Pascals (Pa), atmospheres (atm), torrs (torr), millimeters of mercury (mmHg), or pounds per square inch (psi).

**Quick Fact**

A substance with a density greater than pure water will usually sink in pure water. A substance with a density less than pure water will float.

Likewise, liquids that are immiscible (do not mix) can be layered based on their densities. If oil is poured into a cup with vinegar, the oil will rest on the top because it is less dense than vinegar.

**Quick Fact**

Pressure on the earth changes with altitude. At sea level, the air pressure is about 1 atm or 14.7 pounds per square inch. This means that every square inch of our bodies has almost fifteen pounds (the weight of a heavy bowling ball) pushing on it. At higher altitudes, air pressure drops, so people living in high places will have less pressure on them.

**Quick Fact**

Atmospheric or air pressure is exerted on a surface by the weight of the air above that surface.

**Quick Fact**

Area is a measure of the size of a surface. It is the amount of space inside the boundary of a flat (2-dimensional) object. You can find the area of a rectangle by multiplying its length by its width.

Area = length x width
**ENERGY**: a measure of the ability to do work or generate heat.

- There are many different forms of energy. Some of these forms are mechanical energy, chemical energy, and thermal energy.

- Just like there are many forms of energy, there are also many different ways of measuring energy changes.

- Some common units that scientists use to measure energy changes are Joules (J), calories (cal), and electron volts (eV).

---

**Quick Fact**

A calorie is not a physical object; it is a unit of energy. Most people are familiar with nutritional calories (food calories). A food with a lot of calories is able to supply a lot of energy, while a low-calorie food cannot. The more physical work a person does (like marathon runners), the more calories they need in their food.

Food calories and scientific calories are measured differently. Each calorie listed on a Nutrition Facts food label is actually a kilocalorie (kcal) or 1,000 scientific calories! That’s a lot of energy!
### Measurement

The data that scientists gather from all of these measurements are quantitative. Quantitative data give you amounts. They deal with numbers and tell you how much or how many. On the other hand, qualitative data give you descriptions. They tell you what smell something has or what color it is.

---

#### Physical measurements can typically be classified in two different groups:

- **Extrinsic (extensive) properties**: properties that change based on the amount of substance present. Mass is an example of an extrinsic property. The larger an object, the more mass it has.

- **Intrinsic (intensive) properties**: properties that do not change based on the amount present. Density is an example of an intrinsic property. Pure water in a bucket and pure water in a large pool will have the same density.

---

#### Units of Measurement

Scientists often use a system of measurement known as the metric system. The metric system was developed in France in the 1790s and was the first standardized system of measurement. Before that time, people used many different systems of measurement. One of those systems was the “fps” system (foot, pound, second).
In 1960, the metric system was revised, simplified, and renamed. The updated system was called the Système International d’Unites (International System of Units) or SI system. However, the SI system is still commonly called the metric system. This system is widely used in almost every country around the world, except for the United States. The U.S. uses the U.S. customary units system (inches, quarts, etc.).

When scientists take measurements, they use the SI system. The system allows scientists to easily convert (switch between) large and small numbers.

In the SI system, each unit of measure has a base unit. The seven base units of the SI system are:

<table>
<thead>
<tr>
<th>Measure</th>
<th>Base Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Meter (m)</td>
</tr>
<tr>
<td>Mass</td>
<td>Kilogram (kg)</td>
</tr>
<tr>
<td>Time</td>
<td>Second (s)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Kelvin (K)</td>
</tr>
<tr>
<td>Amount of a substance</td>
<td>Mole (mol)</td>
</tr>
<tr>
<td>Electric current</td>
<td>Ampere (A)</td>
</tr>
<tr>
<td>Luminous intensity</td>
<td>Candela (cd)</td>
</tr>
</tbody>
</table>

Of these base units, the first three (meter, kilogram, second) are called the primary units.

Some things scientists want to measure may be very large. Other things may be very small. To work with either extremely large or small numbers, scientists use metric prefixes. The table below lists some common prefixes and the quantity they represent:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Symbol</th>
<th>Numerical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tera-</td>
<td>T</td>
<td>$10^{12}$ (1,000,000,000,000)</td>
</tr>
<tr>
<td>Giga-</td>
<td>G</td>
<td>$10^9$ (1,000,000,000)</td>
</tr>
<tr>
<td>Mega-</td>
<td>M</td>
<td>$10^6$ (1,000,000)</td>
</tr>
<tr>
<td>Kilo-</td>
<td>k</td>
<td>$10^3$ (1,000)</td>
</tr>
<tr>
<td>Hecto-</td>
<td>h</td>
<td>$10^2$ (100)</td>
</tr>
<tr>
<td>Deca-</td>
<td>da</td>
<td>$10^1$ (10)</td>
</tr>
<tr>
<td>(no prefix)</td>
<td>--</td>
<td>$10^0$ (1)</td>
</tr>
<tr>
<td>Deci-</td>
<td>d</td>
<td>$10^{-1}$ (0.1)</td>
</tr>
<tr>
<td>Centi-</td>
<td>c</td>
<td>$10^{-2}$ (0.01)</td>
</tr>
<tr>
<td>Milli-</td>
<td>m</td>
<td>$10^{-3}$ (0.001)</td>
</tr>
<tr>
<td>Micro-</td>
<td>μ</td>
<td>$10^{-6}$ (0.000001)</td>
</tr>
<tr>
<td>Nano-</td>
<td>n</td>
<td>$10^{-9}$ (0.000000001)</td>
</tr>
<tr>
<td>Pico-</td>
<td>p</td>
<td>$10^{-12}$ (0.000000000001)</td>
</tr>
</tbody>
</table>

Quick Fact
The prefix “deca-” may also be written as “deka-.” The SI spelling is deca-, but the U.S. National Institute of Standards and Technology (NIST) uses deka-. While spellings of the prefixes may be different in different countries, the symbols stay the same. Therefore, a decaliter or dekaliter is always daL.
Prefixes can be added to base units. Prefixes make the value of the unit larger or smaller. For example, one kilometer is 1,000 meters. One millimeter is 0.001 meters.

- **Multipliers**: prefixes greater than one, such as deca–, kilo–, and giga–.
- **Fractions**: prefixes less than one, such as deci–, milli–, and nano–.

New scientific instruments have allowed scientists to measure even smaller and larger amounts. Additional prefixes have been added over the years, such as zepto– \((10^{-21})\) and yotta– \((10^{24})\).

**EXAMPLE:**

If you lined up 1,000 meter sticks from end to end, the full measurement would be 1,000 meters (or 1 kilometer). The kilometer unit is useful for describing long measurements. For example, the distance between Chicago and New York City is approximately 1,300 kilometers.

On the other hand, the average diameter of a human hair is only about 110 millionths of a meter. A micrometer is 1 millionth of a meter. Therefore, the diameter of a human hair is about 110 micrometers (or 110 microns).

Other SI units have been derived (developed) from the seven base units. The table below lists some common derived units:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Derived Unit</th>
<th>Base Units</th>
<th>Derived Unit Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume</td>
<td>Liter</td>
<td>(10^{-3} \times m^3)</td>
<td>L</td>
</tr>
<tr>
<td>Force</td>
<td>Newton</td>
<td>kg (\times m/s^2)</td>
<td>N</td>
</tr>
<tr>
<td>Energy, work</td>
<td>Joule</td>
<td>N (\times m)</td>
<td>J</td>
</tr>
<tr>
<td>Pressure</td>
<td>Pascal</td>
<td>N/m^2</td>
<td>Pa</td>
</tr>
<tr>
<td>Power</td>
<td>Watt</td>
<td>J/s</td>
<td>W</td>
</tr>
<tr>
<td>Electric potential</td>
<td>Volt</td>
<td>W/A</td>
<td>V</td>
</tr>
<tr>
<td>Resistance</td>
<td>Ohm</td>
<td>V/A</td>
<td>(\Omega)</td>
</tr>
<tr>
<td>Frequency</td>
<td>Hertz</td>
<td>1/s</td>
<td>Hz</td>
</tr>
</tbody>
</table>

**EXAMPLE:**

You would like to figure out the force needed to move a toy car. Force is derived from measures of mass and acceleration. The equation is \(F = m \times a\).

You know the car’s mass is 200 grams (0.2 kg). You also know that you want it to accelerate at 3 \(m/s^2\). You then insert those numbers into the equation: \(F = 0.2 \text{ kg} \times 3 \text{ m/s}^2\). You get an answer of 0.6 Newtons.

**Quick Fact**

A large electric eel can produce an electric shock of up to 650 volts at one ampere.
CONVERTING METRIC UNITS

Scientists need to be able to convert measurements between large and small values quickly. The metric system makes conversion simple because prefixes are based on groups of ten.

EXAMPLE:
A person with a headache looks at two bottles of aspirin. One bottle says it has 100 mg of aspirin in each tablet. The other says it has 0.01 g of aspirin in each tablet. Which tablet contains more aspirin? To figure this out, you can convert the measures into the same units.

\[ 0.01 \text{ g} \times \frac{1,000 \text{ mg}}{1 \text{ g}} = 10 \text{ mg} \]

Now we know that the first bottle contains tablets with 100 mg of aspirin, and the second bottle contains tablets with only 10 mg of aspirin. Therefore, the 100 mg tablet contains more aspirin than the 0.01 g tablet.

SCIENTIFIC NOTATION

Quick Fact
Here’s a trick to converting metric units:
To change from one prefix to another, look at the exponents for those prefixes. Subtract the exponent for the first prefix from the exponent for the second prefix. Then, move the decimal point that number of places to the right or left, as appropriate. (Move right to go from larger to smaller numbers. Move left to go from smaller to larger numbers.) Finally, fill in with zeros, if necessary.

For example, to change centimeters \((10^{-2})\) to millimeters \((10^{-3})\), the difference between the exponents is one. Therefore, you would move the decimal one place. You’ll move right to go from the larger centimeter to the smaller millimeter.

\[ 1.0 \text{ cm} = 10.0 \text{ mm} \]

1 centimeter = 10 millimeters

To change micrograms \((10^{-6})\) to milligrams \((10^{-3})\), the difference between the exponents is three. Therefore, you would move the decimal three places. This time, you’ll move left to go from smaller to larger.

\[ 1.0 \mu\text{g} = 0.001 \text{ mg} \]

1 microgram = 0.001 milligrams (or one thousandth of a milligram)
**Scientific notation** is the method scientists use to quickly write numbers very large or very small numbers.

**STEPS FOR LARGE NUMBERS**  
The speed of light in a vacuum is about 300,000,000 m/s. Instead of writing all those zeros, scientists use scientific notation.

1. Write the number as a simple multiplication problem.  
   \[300,000,000 \text{ m/s} = 3 \times 100,000,000 \text{ m/s}\]

2. Write the last number above (one followed by eight zeros) as an exponent using the number 10 as your base number. For example, \(10^2 = 100\) or \(10^3 = 1,000\).

3. Rewrite the number using steps 1 and 2.  
   \[300,000,000 \text{ m/s} = 3 \times 100,000,000 \text{ m/s} = 3 \times 10^8 \text{ m/s}\]

Other numbers can be written in scientific notation. For example, the number of feet in a mile (5,280) would be:  
\[5,280 \text{ ft} = 5.28 \times 1,000 \text{ ft} = 5.28 \times 10^3 \text{ ft}\]

With numbers like the one above, scientists write one number before the decimal point and all other numbers after the decimal point.

**QUICK STEPS FOR LARGE NUMBERS**  
Scientific notation can be as easy as counting. Move the decimal in the appropriate direction. (You will move the decimal to the right for small numbers. You will move it to the left for large numbers.) Then, count the number of places moved to figure out the correct exponent.

Using the feet per mile example—5,280 feet:

1. Move the decimal to the left, so it appears immediately after the first number—5.28.  
2. Since you moved the decimal three places to the left, write the exponent as \(10^3\).  
3. Therefore, 5,280 feet is written as \(5.28 \times 10^3 \text{ ft}\).

**Quick Fact**  
Halley's comet is visible from the earth every 75–76 years. Scientists have estimated that the mass of the comet is approximately 220,000,000,000,000 kilograms. In scientific notation, the mass is written as \(2.2 \times 10^{14} \text{ kg}\). As you can tell, it is much quicker to write the mass in scientific notation. It's much easier to read that way too!
**STEPS FOR SMALL NUMBERS**

Small numbers can be written in scientific notation using a similar process. For example, the average size of grass pollen is 0.000025 meters.

1. Write the number as a simple division problem.
   \[ \frac{0.000025 \text{ m}}{100,000} = \frac{2.5}{100,000} \text{ m} \]

2. Write the number in the denominator (bottom) as an exponent. Again, you’ll use the number 10 as the base for the exponent. For example, \(10^2 = 100\) or \(10^3 = 1,000\).

3. Change the division problem to a multiplication problem by making the exponent negative. For example, \(\frac{1}{100} = \frac{1}{10^2} = 10^{-2}\).

4. Rewrite the number using steps 1, 2, and 3.
   \[ 0.000025 \text{ m} = \frac{2.5}{100,000} \text{ m} = \frac{2.5}{10^5} \text{ m} = 2.5 \times 10^{-5} \text{ m} \]

Therefore, we find that grass pollen has a size of \(2.5 \times 10^{-5}\) m.

**QUICK STEPS FOR SMALL NUMBERS**

To change a small number into scientific notation more quickly, you will use quick steps that are similar to the ones used for large numbers.

Using the grass pollen example—0.000025 meters:

1. Move the decimal to the right, so it appears immediately after the first number (2.5).
2. Since you moved the decimal five places to the right, write the exponent as \(10^{-5}\).
3. Therefore, 0.000025 meters is written as \(2.5 \times 10^{-5}\) m. (We also know that this is the same as 25 micrometers. How do we know this? Move the decimal one more place to the right and adjust your exponent. Now you have \(25 \times 10^{-6}\) meters or 25 micrometers!)

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**Quick Fact**

A normal red blood cell has an average width (diameter) between 6 µm and 8 µm. These numbers can be written as \(6 \times 10^6\) m and \(8 \times 10^6\) m.

If the size of a person’s red blood cells fall outside of this range (either larger or smaller), he or she may have an illness.

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**NOTES**
**SECTION III: CLASSIFICATION OF MATTER**

**OBJECTIVES**
- Classify matter as either a pure substance or a mixture.
- Classify matter into types of mixtures, compounds, and elements.
- Identify the common states of matter and their characteristics.
- Identify and distinguish between physical and chemical properties of matter.
- Differentiate between physical and chemical changes.
- Distinguish between the different phase changes.
- Explain energy as it relates to physical and chemical changes.
- Define and identify several physical and chemical separation processes.

In general terms, chemistry is the study of matter and changes in matter. What is matter? **Matter** is anything that has mass and takes up space. Matter is all around you!

**TYPES OF MATTER**

Matter can be divided into two main categories:

1. **Pure substance**: something that has a specific composition (makeup) that does not change.
   - Pure substances can be either elements or compounds.
   - Pure substances have the same composition throughout.
     - In general, every sample of a certain element has the same intrinsic properties as every other sample of that element. (There are some exceptions. At the nanoscale, gold may appear purple, black, or red. See page 65.)
     - Likewise, every sample of a certain compound generally has the same intrinsic properties as every other sample of that compound.
   - Pure water and carbon dioxide gas are examples of pure substances.

2. **Mixture**: two or more substances that are combined physically. Most of the things around you are mixtures.
   - A mixture can be classified as either homogeneous or heterogeneous (see pages 29–30).
Different parts that make up a mixture have different properties. Tossed salad is a mixture because it is made of different parts—lettuce, carrots, and dressing. Salt water is a mixture, too. It is made of salt and water. However, salt water is a homogeneous mixture, so it looks the same throughout.

The chemical structure (composition) of each part of a mixture stays the same. Therefore, scientists can separate mixtures into their original parts (see the subsection on Physical and Chemical Separations).

The different parts of a mixture are arranged randomly.

**EXAMPLE:**
Salt and water can be combined to form salt water. The properties of the mixture may be different than the properties of each part. (Pure water looks clear, but salt water may look cloudy.) However, the chemical structure of each part in the mixture stays the same. The mixture still contains water (H₂O) and salt (NaCl). Therefore, you can heat the salt water to make the H₂O change from a liquid to a gas (see the subsection on Physical Changes). The salt in the mixture makes the salt water take longer to boil than pure water. Still, the pure water will eventually vaporize, leaving the salt behind.

**PURE SUBSTANCES**

**Element:** a pure substance that cannot be broken down by normal chemical or physical means. Elements are considered the simplest substances. An element is made of only one type of atom. It is identified by its atomic number (see the Atomic Structure section). An element’s atomic number sets it apart from other elements.

- All matter is made up of elements or combinations of elements.

- **Allotropes:** different forms of the same element in the same physical state of matter.
  - Allotropes contain only one type of atom. However, the way that the atoms are arranged is different. Therefore, the different arrangements of atoms give the allotropes different properties.
  - Each allotrope is a pure form of that element.

**EXAMPLE:**
Two solid allotropes of carbon are graphite (pencil lead) and diamond. They are both solid forms of carbon. However, graphite is a dark gray, waxy substance. Diamond is a hard, clear substance. Why are two solid forms of the same element so different? The answer is that the carbon atoms are arranged in a different pattern.

- Only certain elements have allotropes. Some of those elements are carbon, oxygen, tin, phosphorus, and sulfur. Oxygen has two gaseous allotropes. They are O₂ (diatomic oxygen) and O₃ (ozone). Two solid allotropes of tin are gray tin and white tin.

Quick Fact

The water that comes out of your kitchen sink is not a pure substance. This water is called tap water. It usually contains minerals or other substances so tap water is actually a mixture. Water that is considered a pure substance is called distilled water or pure water.
Oxygen was discovered by Swedish chemist Karl Scheele and English chemist Joseph Priestley. Both discovered oxygen separately and are given credit for the discovery.

**Characteristics:**

- Makes up two-thirds of the human body by weight, mostly in the form of water.
- Is the most common element in the earth’s crust.
- Is essential for oxidation processes, such as respiration, combustion, and rusting.
- Has two gaseous allotropes:
  1. **Diatomiac oxygen** \((O_2)\): a colorless and odorless gas that makes up 21% of air by volume. It is often called simply *oxygen gas*.
  2. **Ozone** \((O_3)\): formed by electrical discharges (lightning) or ultraviolet (UV) radiation that acts on diatomic oxygen in the atmosphere. Ozone forms a thin protective layer in the upper atmosphere. That layer helps block UV radiation from reaching the earth’s surface. Therefore, high amounts of ozone in the upper atmosphere are very helpful. In the lower atmosphere (ground level), high amounts of ozone can be unhealthy.

Oxygen is a very active element. Most elements combine with oxygen to form compounds. Many of those compounds have names ending in “–ite” or “–ate,” such as nitrites \((-NO_2)\) and sulfates \((-SO_4)\). Oxygen is the second most electronegative element! (See the subsection on Periodic Trends from the Passport to Science Exploration: Chemistry Connections.)
According to archeological findings, tin is one of the oldest metals used by humans. Tin has been found in utensils and weapons (in the form of brass) dating back to 3,500 B.C. The atomic symbol for tin comes from the Latin name “stannum,” which means tin.

**Characteristics:**

- Is a silvery-white metal with a highly crystalline structure.
- Found mainly in the mineral cassiterite (SnO₂).
- Is very malleable and ductile (see the subsection on Types of Chemical Bonds from *Chemistry Connections*).
- Has 10 stable isotopes—the largest number of stable isotopes on the periodic table (see the subsection on Isotopes).
- Has two solid allotropes:
  1. **White tin** (beta tin): the familiar silvery-white metallic form. White tin is stable at and above a normal room temperature.
  2. **Gray tin** (alpha tin): a brittle gray powder. Gray tin is a nonmetal. It is stable at about 13.2 °C (56 °F).

Tin resists corrosion from water and air but not from acids or alkalis. Therefore, it is used as a protective coating on other metals. “Tin cans” are actually made of steel that is coated with tin.

**Quick Fact**

When a tin bar is bent, the crystal structure is disrupted. As a result, a soft crackling sound can be heard. This sound is known as the tin cry.

**Quick Fact**

Stannous fluoride (SnF₂) is used in some types of toothpaste. It helps make tooth enamel more resistant to attacks from acids, such as the citric acid in orange juice.

**Compound:** a pure substance made up of two or more elements joined in a defined ratio.

- In nature, most elements are found in combination with other elements. They are found as compounds.
- Pure water is a compound of hydrogen and oxygen atoms bound together in a 2:1 ratio. The ratio means that 2 hydrogen atoms are joined to 1 oxygen atom. Therefore, the chemical formula for water is H₂O. Other familiar compounds include table salt (NaCl), glucose (C₆H₁₂O₆), and sulfuric acid (H₂SO₄).
- There are millions of different known compounds. Scientists develop and study new compounds every day.
- A **binary compound** is made up of two elements, such as sodium chloride (NaCl) and carbon dioxide (CO₂). A **ternary compound** is made up of three elements, such as glucose (C₆H₁₂O₆) or silver carbonate (Ag₂CO₃).
HISTORY: **JOHN DALTON** (1766–1844)

John Dalton developed the atomic theory of matter. This theory became the basis for all future models of the atom. Dalton’s four-part atomic theory states that:

- All matter is made up of indivisible particles called atoms.
- All atoms of a certain element are identical. Atoms of different elements have different properties.
- Chemical reactions involve the combination or rearrangement of atoms, not the destruction of them.
- When elements react to form compounds, they react in defined, whole-number ratios.

In addition to his theory on matter, Dalton conducted studies on gases. Dalton’s studies on gases led him to develop the law of partial pressures, known as Dalton’s Law.

- **Dalton’s Law**: the total pressure of a mixture of gases equals the sum of the pressures of the gases in the mixture, with each gas acting independently.

\[ P_{\text{total}} = P_1 + P_2 + P_3 + \ldots \]

**MIXTURES**

**Homogeneous mixture**: a type of mixture that is considered to be the same throughout. Homogeneous mixtures are mixed evenly. Therefore, each part of the mixture seems to be the same.

**EXAMPLE:**

Apple juice is a homogeneous mixture. The juice at the top of your glass is the same as the middle and the bottom. The juice looks the same in every part of the glass. Any sip of the juice should taste the same.

- Brass and bronze are examples of homogeneous mixtures made of metals. They are metal **alloys** (see the Industrial Applications of Chemistry section from Chemistry Concepts in Action).

- In liquid or gas form, homogeneous mixtures are usually called **solutions** (see the subsection on Chemicals by Volume—Solutions from Chemistry Connections).

  - **Solution**: a homogeneous mixture in which one or more substances (solute) are dissolved in another substance (solvent). Solutions are made up of elements or compounds mixed together at a very fine level (molecular level).

  - **Solute**: the substance that is dissolved in the solution. The solute is mixed into the solution completely so that it seems to almost disappear. The solute is usually the substance that is present in a lesser quantity. (There is usually a smaller amount of it in the solution.)

  - **Solvent**: the substance that does the dissolving. The solvent is usually the substance that is present in a greater quantity. (There is usually a greater amount of it in the solution.)
EXAMPLE:
Dissolving salt into water creates a saltwater solution. In salt water, the solvent is water. The solute is salt.

Some solutions may have more than one solute dissolved in the solvent. Soda pops are homogeneous mixtures made up of many different solutes. These solutes include sugar and carbon dioxide gas. These solutes are all dissolved in water (the solvent).

• Some substances will dissolve more easily than other substances.
  – A substance that dissolves in another substance is soluble. Salt and ethanol are soluble in water.
  – If a substance does not dissolve, it is insoluble. Butter and other lipids are insoluble in water (see the subsection on Chemistry in the Human Body from Chemistry Concepts in Action).
  – Just because a substance is soluble in one thing does not mean it is soluble in everything. While salt is soluble in water, it is insoluble in oil.

Heterogeneous mixture: a type of mixture in which the makeup is not the same throughout. Heterogeneous mixtures are not mixed evenly. They may not appear uniform. (They do not appear to be the same all the way through.)

EXAMPLE:
A peanut butter and jelly sandwich is a heterogeneous mixture. You can see the different layers of bread, peanut butter, and jelly.

Another example of a heterogeneous mixture is beach sand. Surprised? If you look closely, you’ll be able to tell. You can see different colors from the different substances (shells, pebbles, etc.) in the beach sand. No two handfuls of the sand are exactly the same.

Some mixtures are not classified simply as homogeneous or heterogeneous.

Colloid: a mixture in which very small particles are spread evenly through another substance. The particles in a colloid usually have a size of about one micrometer to one nanometer. Because of the tiny size of those particles, some colloids look like solutions. However, the particles in a solution are even smaller than the particles in a colloid. (Particles in a solution are more like the size of molecules. Think nano and smaller!) You just can’t see this difference without a powerful microscope.

• Colloids consist of fine particles of one substance mixed into another. The fine particles in a colloid are suspended and dispersed throughout the substance.
• **Sols**: colloids made of fine solid particles in a liquid or another solid.
  - Paints, muddy river water, and sewage are liquid sols.
  - Pearls, colored glass, and pigmented plastics are solid sols.

• **Gels**: consist of liquids spread throughout a solid, such as jelly, butter, and cheese.

• **Foams**: consist of gases finely spread throughout liquids or solids.
  - Whipped cream and soda pop foam are liquid foams.
  - Marshmallows and Styrofoam are solid foams.

• **Aerosols**: colloidal suspensions of liquid or fine solid particles in a gas.
  - Fog, mists, clouds, and sprays are aerosols with liquid particles.
  - Smoke is an aerosol with solid particles.

• **Emulsions**: consist of liquids spread throughout other liquids. Examples include oil and vinegar salad dressing, hand cream, and mayonnaise.
  - Emulsions often have a cloudy appearance. The boundary between the different parts of the emulsion scatters the light that passes through it.
    If you pour vinegar and then oil in a glass, the oil will rest on top of the vinegar. If you look at the boundary between the oil and vinegar, it will look cloudy.
  - Emulsions are often unstable. Homemade oil and vinegar salad dressing is an unstable emulsion. It will quickly separate unless you shake it continuously. Shaking the emulsion keeps the parts mixed. However, the oil and vinegar do not want to be mixed together. Droplets of oil will try to find and combine with other oil droplets. The oil droplets will continue to combine with each other until they are completely separated from the vinegar. When small droplets recombine to form bigger ones, the process is called **coalescence**.

**Quick Fact**: A bubble is a single ball of gas in a liquid. In carbonated drinks, like soda pop, you can see bubbles of CO₂ gas in the liquid.

**Quick Fact**: Sometimes, it is hard to figure out if a mixture is heterogeneous, homogeneous, or a colloid. For example, the amount of salt in ocean water may be different in different places. Scientists would not say the ocean is completely homogeneous. Water samples taken from 50 feet below the surface and from 200 feet below the surface will not be exactly the same. Can you think of other substances that are hard to classify as one or the other?

What about milk ... is it homogeneous, heterogeneous, or something else?

**Quick Fact**: The **Tyndall effect** is the scattering of light by colloid particles. It occurs when the particles spread throughout liquid and gas colloids are large enough to scatter light but small enough that they do not settle. It is the reason you can see car headlight beams from the side on a foggy night.
The following flow chart displays a summary of the different types of matter:

**MATTER**

- **Pure Substance**
  - **Compounds** (NaCl, CO₂)
  - **Elements** (H, Fe, C)

- **Mixture**
  - **Homogeneous** (soda pop, brass)
  - **Heterogeneous** (pizza, salad)

**PROPERTIES OF MATTER**

Scientists sort matter by its physical and chemical properties. These properties also help scientists identify unknown substances. We use our senses or take measurements to identify physical properties. We make observations and perform experiments to identify chemical properties. Specifically, we look at how a substance reacts with other substances.

**PHYSICAL PROPERTIES**

A physical property is a property of matter that can be observed without changing the substance into another substance. Some examples of physical properties are density, color, boiling point, and melting point.

- At a constant temperature and pressure, the density of a substance does not change. One gram of lead at 20 °C has the same density as 500 grams of lead at 20 °C. As a result, density is often used to identify unknown substances. It is also a property that can be identified easily by taking measurements.

- Color is another property used to determine an unknown substance. Most substances are known to be a specific color. For example, an emerald is a type of mineral with a green color.

- The melting and boiling point of a substance stay the same at standard pressure. For example, the melting point of mercury is approximately -38.8 °C. The boiling point of mercury is approximately 356.7 °C.

Quick Fact: Standard temperature and pressure (STP) are the conditions often used to study or test a substance. STP is 0 °C and 1 atm (101.335 kPa or 14.7 psi). These values are the approximate freezing point of water and atmospheric pressure at sea level.
CHEMICAL PROPERTIES

A chemical property is determined by the ability of a substance to react with or change into another substance. A chemical reaction may take place when substances interact. During a chemical reaction, the structure or chemical makeup of a substance changes (see the subsection on Chemical Changes). Therefore, chemical properties are often identified after a chemical reaction takes place. Some examples of chemical properties are toxicity, flammability, and reactivity with other substances.

• Toxicity is the potential of a substance to have a harmful effect on an organism. The only way to determine toxicity is by observing how a substance reacts with other substances. (Thus, it is a chemical property!)

• Flammability describes the ability of a substance to catch fire (ignite) or burn. Solids, liquids, and gases can all be flammable.
  - Ethanol is a highly flammable liquid. It can catch fire easily. On the other hand, water is a nonflammable liquid.
  - In general, certain conditions are needed for a fire to occur. These conditions make up the “fire triangle.”
    • The first is fuel. Flammable chemicals are a type of fuel.
    • The second is oxygen. Fires need oxygen to burn. Air can provide oxygen, as well as chemical oxidizers or oxygen tanks.
    • The third is energy. Enough energy must be present to start the reaction.

• The reactivity of a substance is its ability to interact or change when it comes in contact with other substances or conditions. For example, an iron object will form a reddish-brown coating when left outside for a long time. The iron reacts with the oxygen and water vapor in the air.

Quick Fact
Toxicity is often related to the amount of a substance. Vitamins are generally important for keeping us healthy. However, they can be toxic in extremely large quantities.

Quick Fact
Inflammable actually means the same thing as flammable! Inflammable is an older term used to describe substances that ignite or burn easily. Unfortunately, many people mistake inflammable to mean not flammable. Today, warning symbols generally use the term flammable to avoid that confusion. Nonflammable is the term used to describe substances that are not flammable.

Quick Fact
Some substances are EXTREMELY flammable. White (or yellow) phosphorous can spontaneously ignite in air without any energy change or spark! It should be handled with extreme care and stored in a sealed container under water and away from heat!
STATES OF MATTER

Matter can also be classified based on its state. The most familiar states of matter are solids, liquids, and gases. For example, ice, water, and water vapor are all H₂O in different physical states. As heat is added or removed, the matter may undergo a change of state or a phase change (see page 39).

SOLIDS: have a definite volume and a definite shape. A brick, a table, and a pencil are examples of solids. If you put a brick or pencil in different size containers, they will stay the same size and shape in each container.

- The particles that make up a solid are usually locked into place. They are packed tightly together. However, the particles are still moving slightly. They vibrate or move back and forth slightly in their place. (You can think of yourself as a particle. If you are sitting at your desk and waving your hands, you are in the same place, but you are moving. You are a solid particle.)

- The solid state of a substance is generally denser than the liquid and gaseous states.
  
  - Solid gold has a density of approximately 19.3 g/cc at 20 °C. Liquid gold has a density of approximately 17.3 g/mL at its melting point.
  
  - Solid CO₂ has a density of approximately 1.56 g/cc. at -78.5 °C and 1 atm. Liquid CO₂ has a density of approximately 0.77 g/mL at -56.6 °C and 4 atm. Gaseous CO₂ has a density of approximately 0.0018 g/mL at 20 °C and 1 atm.
  
  - One exception is water. When you put ice in water, the ice floats. Liquid water has a density of 1 g/mL at 4 °C. When it freezes at 0 °C, its density actually drops to about 0.9 g/cc.

- Crystalline solids are made up of atoms or molecules that are organized in specific repeating patterns. These regular, repeating patterns form crystals.
  
  - Crystalline solids have a definite melting point. Therefore, they change rather quickly from a solid to a liquid when heated above their melting point. This physical property can be used to determine the purity of the crystalline solid.
  
  - Diamonds, ice, and table salt are crystalline solids.

Quick Fact

Table sugar (sucrose) can be an amorphous solid, such as cotton candy. It can also be a crystalline solid, such as the small crystals that are often found in kitchen sugar bowls. Why? It mainly depends on how the sugar is treated. If sugar is melted and then cooled quickly, the molecules do not have enough time to organize into a definite crystalline structure. Instead, they stop moving (except for slight vibrations) and become an amorphous solid.
• **Amorphous solids** are also made up of atoms or molecules that are locked into place. However, those atoms or molecules do not organize into a specific form or neat, repeating structure.
  
  – Most amorphous solids do not have a definite melting point. Instead, they generally soften and become more flexible when heated.
  
  – Glass is an example of an amorphous solid. It is mainly made up of silicon dioxide (SiO₂).
  
  – Wax, rubber, and many polymers, including polystyrene, are amorphous solids (see the subsection on **Polymers** from *Chemistry Concepts in Action*).

**LIQUIDS:** have a definite volume but no definite shape. Water and milk are examples of liquids.

• A liquid will take the shape of its container. If there is not enough liquid to fill the entire container, the liquid will take the shape of the part of the container it fills (the bottom).

• A liquid cannot change its overall volume.

• The particles that make up liquids are in constant random motion. (They move more than the vibrating solid particles. They actually slide past one another and can move over larger distances).

• Even though liquid particles move around more freely compared to particles in solids, the particles in liquids tend to remain fairly close to one another.

• **Viscosity** is a property of liquids that describes the “thickness” of the material. It is a measure of the liquid’s resistance to flow. The less viscous a liquid is (the lower its viscosity), the more easily it flows.
  
  – Water has a low viscosity. When you pour water from one container to another, it flows quickly.
  
  – Honey has a high viscosity. When you pour honey from one container to another, it flows slowly.
  
  – The ability of a material to flow is related to the strength of the bonds between the liquid molecules. The stronger the bonds, the more difficult it is for the liquid to flow (see the subsection on **Intramolecular Forces** from *Chemistry Connections*).

• **Surface tension** is a property of liquids that describes the attraction of liquid molecules at the surface. (It brings the molecules closer together at the surface.) The strong attraction of molecules at the surface of the liquid creates a surface “film.” This film makes moving an object through the surface of a liquid more difficult than moving the object when it is completely submerged in the liquid.
  
  – Surface tension causes liquids to keep a low surface area. For example, soap bubbles and rain droplets form the shape of a sphere rather than spreading out flat.

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**Quick Fact**

**Silicon dioxide** can have a crystalline structure, such as in quartz. However, when it is cooled quickly, it does not completely crystalize. Instead, it forms glass or glassy silica. Studies have shown that the SiO₂ in glass has some type of structure but not a specific, repeating one. Therefore, glass is still considered an amorphous solid.
Water has a very high surface tension because of strong hydrogen bonding. Its surface tension is about 0.073 N/m. Oil has a much lower surface tension than water. Its molecules are only weakly attracted to each other. If you pour a spoonful of vegetable oil on one plate and a spoonful of water on another plate, the water does not spread as far as the oil. This happens because the water molecules are strongly bound together.

**GASES:** have no definite volume and no definite shape. For example, the air around you is a mixture of gases.

**EXAMPLE:**

The air around us is mainly made up of nitrogen (N\textsubscript{2}) and oxygen (O\textsubscript{2}). Approximately 78% of the air around us is N\textsubscript{2}. About 21% of the air is O\textsubscript{2}. The remaining 1% includes argon, CO\textsubscript{2}, water vapor, and other gases.

- If a gas is put into a container, it will take the shape of the entire container. Unlike a liquid, the gas will not just stay in the bottom. A gas will fill the container completely.

- Gas particles do not have strong attractions between them. Therefore, they move about quickly in random directions. They move over very large distances. They can also go a lot farther without hitting another particle than particles in a liquid can.

- Gas particles will not stay close to one another for any length of time.

- Because of the extra space between the particles, gases are easily compressed.

- **Effusion** is the process by which gas particles flow through small holes in a container.

  - **Molecular mass** is the mass of one molecule of a substance.

  - According to Graham’s Law, gases with a lower molecular mass effuse more quickly than gases with a higher molecular mass. (You can think of it in terms of people. It is easier for a smaller person to squeeze through a tight space than it is for a larger person.)

**EXAMPLE:**

Two balloons are filled to the same size with different gases. One is filled with oxygen. The other is filled with hydrogen gas. Without being disturbed, the hydrogen gas balloon deflates faster because hydrogen gas molecules have a smaller molecular mass. The hydrogen molecules can escape (effuse) more quickly than the oxygen molecules.
- **Diffusion** is the movement of particles from an area of high concentration to an area of low concentration. (The particles move from an area with a lot of other particles to an area with few particles.) This movement is a result of the particles’ kinetic energy (see the subsection on Energy Changes).

  - During diffusion, particles move at random. The particles leave highly concentrated areas and enter less concentrated areas. Diffusion will continue until the particles are spread evenly throughout the area. Particles will continue to move, but overall they will be evenly spread throughout the container.

  - The particles of fluid substances can undergo diffusion.

**EXAMPLE:**

If you add a drop of red food coloring to a glass of water, the food coloring will diffuse. It will spread through the water until the water is evenly colored red.

Likewise, on your way to school in the morning, you smell the strong odor of skunk spray. On your way to school the next day, you most likely won’t smell the odor anymore. Diffusion (and air movement—wind) causes the odor to become weaker over time as it spreads through the air.

The process of diffusion is illustrated below:

**Quick Fact**

Osmosis is the diffusion of water across a semi-permeable membrane (a membrane that allows some ions or molecules to pass through, but not others).

Osmosis is an important biological process because it allows water to pass in and out of cells.
Like concentration, other factors can affect the rate of diffusion. These include temperature and the size of the particles.

- In general, particles will diffuse more quickly at higher temperatures. Therefore, a drop of food coloring will diffuse more quickly in a cup of hot water than in a cup of cold water.
- Smaller particles diffuse more quickly than larger particles.
- Particles will diffuse faster when there is a bigger difference in the concentration of two areas. Using the diffusion process image on the previous page, the particles diffuse faster when the barrier is first removed. As the particles spread out evenly, the rate of diffusion becomes slower.

Along with the three familiar states of matter (solids, liquids, and gases), there is another less familiar state, called plasma.

**PLASMA:** an ionized gas. Some electrons in plasma atoms are free. This means they are not bound to the atom or molecule (see the Atomic Structure section).

- The positive and negative charges in plasma move somewhat freely. Therefore, plasma can conduct electricity and respond strongly to electric or magnetic fields.
- Plasma occurs under high-energy situations. For example, the extreme heat associated with lightning or the interior of stars produce plasma.
- Plasma usually takes the form of neutral gas-like clouds.
- Today, people can buy plasma televisions. These televisions are called “plasma” TVs because the technology uses small cells that contain electrically-charged ionized gases.

**PHYSICAL CHANGES**

Matter often changes, and these changes can be either physical or chemical.

**Physical change:** any change in a substance’s form that does not change its chemical makeup. The chemical formula of the substance stays the same before and after the change.

- Tearing or cutting a piece of paper into smaller pieces is an example of a physical change. The paper is in smaller pieces, but the chemical makeup of the paper has not changed.
CHANGES OF STATE—TEMPERATURE

Another example of a physical change is when matter changes from one state to another. These changes are often called phase changes. They are a result of changes in temperature or pressure.

Melting: a change in state from a solid to a liquid.

• Melting point: the temperature at which a substance begins to change from a solid to a liquid.

EXAMPLE:
At very low temperatures (0 °C or below), water molecules have very low energy, so the water becomes a solid. The most common solid form of water is called ice.

As the temperature increases, energy enters the solid ice. The energy releases the molecules from ice crystals. This allows the molecules to move around freely, while still remaining in contact. When this occurs, ice melts to become liquid water.

• At one atmosphere (1 atm) of pressure, the melting point of ice is 0 °C or 32 °F. The melting point of silver is approximately 961 °C.

– The term "atmosphere" means the air pressure at sea level. It is used as a unit of measurement for pressure.

Freezing: a change in state from a liquid to a solid.

• Freezing point: the temperature at which a liquid begins to form a solid. The substance will remain at that temperature until freezing is complete.

• At 1 atm of pressure, the freezing point of water is 0 °C. As you can see, the melting point and the freezing point of a substance are generally the same.

EXAMPLE:
A bottle of juice has been sitting on the counter. The juice is now at room temperature, but you want to cool it. Therefore, you put the juice in the refrigerator. Since the refrigerator is cooler in temperature, energy will leave the juice. This makes the juice cooler. If you want to cool the juice very quickly, you might put it in the freezer. Just don't forget and leave it there too long. If too much energy leaves the juice, it will become a solid! (In fact, you can make popsicles by putting juice in an ice tray and letting it freeze in the freezer!)

Quick Fact
The freezing point of a liquid can be lowered by adding a nonvolatile solute. For example, the freezing point of water can be lowered by adding salt. As more salt is added, the freezing point becomes lower. The lower freezing point makes it more difficult for the liquid to freeze. Roads are salted or sanded in cold weather to prevent ice from forming.

Think About It...
Have you ever left a glass of ice water sitting out on a warm day and noticed that the ice got smaller or completely disappeared? The ice didn’t actually disappear, so what happened?
Vaporization: a change in state from a liquid to a gas. The two main types of vaporization are evaporation and boiling.

- **Evaporation**: a vaporization process that occurs at the surface of a liquid.

  **EXAMPLE:**
  A puddle forms on the ground after it rains. The water molecules in the puddle gain energy from the ground and the sun. As the water molecules gain energy, some of the molecules at the surface of the puddle change into a gaseous state and escape (evaporate!) into the air. As a result, the puddle will get smaller as time passes.

- **Boiling**: a vaporization process in which a liquid changes to a gas both below the surface and at the surface of the liquid. During this process, bubbles of gas form and escape from the liquid.

  **Boiling point**: the temperature at which a liquid begins to form a gas. Once a liquid begins to boil, its temperature will remain the same until all of the liquid changes to a gas.

  At 1 atm of pressure, the boiling point of water is 100 °C or 212 °F. The boiling point of ethanol is approximately 78.3 °C.

  **EXAMPLE:**
  When liquid water is heated on a stove, the water molecules throughout the liquid gain energy. Water molecules change to a gaseous state and escape into the air. Vaporized water molecules below the surface form bubbles within the liquid and rise. The gaseous state of water is known as water vapor.

  **Boiling point varies with atmospheric pressure.**
  - When the atmospheric pressure is lower, less energy is needed for the particles of liquid to change into a gas and escape into the air.
  - Therefore, at high altitudes (such as on top of a mountain) where atmospheric pressure is lower, a material will boil at a lower temperature.
  - The “normal boiling point” (nbp) is the temperature at which the vapor pressure of a liquid equals 1 atm.

**Quick Fact**

Water vapor is a colorless gas. It is invisible. The white “cloud” or “mist” that you see rising from a tea kettle or steam engine is actually liquid water droplets suspended in the air. It appears to be white because the light scatters off of the water droplets like clouds in the atmosphere. This “mist” is commonly called steam.

**Quick Fact**

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**Quick Fact**

The boiling point of a liquid can be increased by adding a nonvolatile solute, such as pouring salt into water. As more salt is added, the boiling point becomes higher. Therefore, people living high on a mountain often like to put salt in their water. This causes the water to boil at a high enough temperature for proper cooking.
**Condensation**: a change of state from a gas to a liquid.

- **Dew point**: the temperature at which a gas begins to condense into a liquid.

**EXAMPLE:**

When energy is removed from water vapor, the vapor cools and condenses into liquid water.

If the temperature drops in the evening after a hot summer day, the water vapor in the air cools. As the cooler air gets closer to the surface of the earth, it will likely come in contact with a surface. As the water vapor touches the surface, it cools even more and condenses. When this happens, droplets of liquid water are left on the surface, such as grass.

If it is cold enough, you may see frost on the grass instead of dew. (Read on to learn about deposition.)

**Sublimation**: a change of state directly from a solid to a gas. During sublimation, the substance does not pass through the liquid state.

- The sublimation of water is difficult to see because it happens so slowly. However, you may have noticed that ice cubes in the freezer get smaller over time, even though the temperature stays below the freezing point of water. The water molecules from the ice cube (solid phase) eventually escape to the gas phase.

- The sublimation of solid carbon dioxide (known as dry ice) or iodine crystals can be seen more easily.

**Deposition**: a change of state directly from a gas to a solid.

**EXAMPLE:**

When frost forms on car windows at low temperatures, deposition has occurred. As water vapor in the air comes in contact with the freezing cold window, it turns directly to ice crystals.
CHANGES OF STATE—PRESSURE

Phase changes occur because a substance has been given energy or energy has been taken away. One way to give a substance energy is through temperature. Another way is through pressure.

EXAMPLE:
Placing a heavy object on a block of ice causes the ice to melt.

Quick Fact
Volatility is a measure of how quickly a substance vaporizes at a certain temperature. It can refer to BOTH solids and liquids (sublimation and vaporization). For example, dry ice (solid CO$_2$) is highly volatile. It sublimes into a gas at room temperature. Likewise, gasoline has a much higher volatility than water. It will vaporize more quickly than water.
CHEMICAL CHANGES

Chemical change: a change that takes place when atoms of a substance are rearranged. The bonds between the atoms are broken or formed. When a chemical change takes place, the ending substance or substances are different from the starting substance or substances. It is a change in matter that produces one or more new substances.

- Chemical changes involve more than just a change in form. A chemical change involves a reaction in which the structure or composition (makeup) of the material changes.
- Chemical changes almost always take place with energy changes.
- Chemical changes also involve the restructuring of how electrons hold the various atoms together.
- In some cases, chemical changes can be seen by a color change. In other cases, it can be hard to tell if a chemical change has taken place.

EXAMPLE:
A chemical change occurs when iron rusts. The iron reacts with oxygen (in the presence of water) in the air. The reaction forms iron oxide, a reddish-brown substance commonly called rust which has different properties than the iron.

Other examples of chemical changes are the burning of fuel and the baking of a cake.

ENERGY CHANGES

Physical and chemical changes involve energy (see the Energy section from Chemistry Concepts in Action).

Energy: the ability to do work or produce heat.

- Energy is usually measured in “calories” or “Joules” (see the Measurement section).
- Energy may take a variety of forms. The most common form is thermal energy. Thermal energy is the total energy of the particles in an object that respond to changes in temperature. The transfer of thermal energy is known as heat flow or heat transfer (see the Energy section from Chemistry Concepts in Action).
- Energy is present in light, sound, electricity, chemical bonds, and much more.
• Matter changes whenever energy is added or taken away. Although the energy is added or taken away, the overall amount of energy remains the same. It simply changes form.

**EXAMPLE:**

If you put a ball on a shelf, it contains potential energy (stored energy). If the ball rolls off the shelf, it may bounce a few times and stop. During that time, the potential energy was converted into a few other types of energy. The energy changed from potential to kinetic (energy of motion) as the ball fell. The energy also changed to sound energy (what you hear when the ball bounces).

In every physical and chemical change, the total amount of energy stays the same. This principle is called the law of conservation of energy. It is also known as the first law of thermodynamics (see the Energy section from *Chemistry Concepts in Action*).

**Law of conservation of energy (first law of thermodynamics):** energy easily changes from one form to another, but it cannot be created or destroyed.

**EXAMPLE:**

The energy stored in the tip of a match is in the form of stored chemical energy. When you light the match, the chemical energy becomes light energy and thermal energy.

**PHYSICAL ENERGY CHANGES**

During phase changes, energy may be added to or removed from a substance. This means the energy is transferred between a substance and its surroundings.

*Mechanical energy* is another form of energy. It is determined by the motion or position of a substance. The total mechanical energy of a substance is the sum of its kinetic and potential energy.

**Kinetic energy (KE):** energy of motion.

• If you know the mass and velocity (speed) of an object, you can determine its kinetic energy. To do so, use the equation below:

\[
KE = \frac{\text{(mass)} \times (\text{velocity})^2}{2} \quad \text{or} \quad KE = \frac{1}{2} \text{mv}^2
\]

• The faster an object is moving, the more kinetic energy it has. Notice the important role of velocity. If you double the mass of an object, you double its kinetic energy. However, if you double the velocity of the object, you quadruple its kinetic energy!
Potential energy (PE): stored energy.

- A ball at the top of a hill has potential energy. If it began to roll down the hill from the force of gravity, it would gain kinetic energy but lose potential energy.

- If you know the mass, gravity, and height of an object, you can determine its gravitational potential energy. To do so, use the equation below:

\[ PE = mgh \]

CHEMICAL ENERGY CHANGES

Like physical changes, chemical reactions involve the gain or loss of energy. Chemicals have energy (just like a ball on a shelf). When a chemical substance undergoes a reaction, it may lose some energy. (Think of it like the ball losing potential energy as it falls.) In other reactions, the chemical may gain some energy. (Think of it like the ball gaining potential energy when someone puts it back on the shelf.)

Many chemical reactions involve the absorption or release of thermal energy. Thermal energy usually moves from warmer areas to cooler areas.

- Exothermic change: a change that gives off energy.
  - Any burning reaction is an exothermic reaction because it releases thermal energy. These reactions include lighting a match and burning coal or other fuels.

- Endothermic change: a change that needs energy to be added.
  - If a substance becomes cold after a chemical reaction or physical change, then the change was endothermic. An example is melting ice.
  - Nitrogen gas will not combine with oxygen gas in the atmosphere at standard temperature and pressure. However, nitrogen gas and oxygen gas will combine to form nitrous oxide when energy is added. Therefore, the formation of nitrous oxide is an example of an endothermic chemical reaction.

PHYSICAL AND CHEMICAL SEPARATIONS

Matter can be classified as pure substances or mixtures. These pure substances and mixtures may be in different states.

It is important for scientists to be able to separate mixtures into their original parts. To do this, they use separation processes.

Separation process: a process that divides a mixture into two or more different parts.

- A separation process uses the different properties of the mixture’s parts to get the parts to separate.
EXAMPLE:
A mixture of rocks and pebbles could be separated by using a screen. The screen would allow the tiny pebbles to fall through, but not the large rocks. The property used for separation is size.

Pieces of iron could be separated from plastic in a recycling center using a magnet. The property used for separation is magnetism.

PHYSICAL SEPARATIONS
Physical separations use physical properties to separate the parts of a mixture. This is done without changing the chemical properties of the parts. There are many physical separation processes (see the Laboratory Separations section from Chemistry Concepts in Action).

**Filtration** is a way of separating a mixture based on the sizes of the parts that make up the mixture. Filtration uses the size difference between the particles that make up one substance and the particles that make up another substance.

- In a laboratory, scientists often use filter paper to separate particles in a liquid. The filter paper comes in many grades. These grades represent the size of the tiny holes (pores) in the paper. Different pore sizes are available. A big pore size allows larger particles to pass through, but traps the very biggest particles. A small pore size allows small particles to pass through, but captures the larger particles.

  - The filter paper is folded into a cone and placed in a funnel.
  - A liquid that contains solid particles is poured through the filter paper into a container (usually a flask). The particles may be resting at the bottom of the liquid. They may also be floating on top or suspended throughout the liquid.
  - The particles in the solution are trapped by the paper. The liquid flows through the paper and collects in the flask below.
  - The collected liquid is called the filtrate. The filtrate is free of the solid particles.

EXAMPLE:
One example of filtration (without the use of filter paper) occurs commonly in people's kitchens. Pasta is cooked in a pot of water on a stove. Once it is cooked, the mixture is poured through a colander. The colander traps the pasta but lets the water pass through.
CHEMICAL SEPARATIONS

Chemical separations require some type of chemical reaction to take place.

**Precipitation:** a means of separating a component in a solution by reacting it with another substance to form a solid.

- After the chemical reaction occurs, the solid that forms from the solution is called a precipitation.
- If the solid particles are very small, they may remain in suspension. These particles can then be separated by filtration.

**EXAMPLE:**

One example of a chemical separation through precipitation involves water purification. Sometimes, lead (Pb²⁺) has a way of getting into the water supply and needs to be removed because it is hazardous to your health. Chemists can accomplish this by adding sulfides (S²⁻) or sulfates (SO₄²⁻). These substances will combine with the lead to make a new solid compound.

\[
\text{Pb}^{2+} + \text{S}^{2-} \rightarrow \text{PbS} \\
\text{Pb}^{2+} + \text{SO}_4^{2-} \rightarrow \text{PbSO}_4
\]

Once the solid compound is formed, the lead (which is part of the solid compound) can be removed from the water by filtration. As you can tell, chemical separations can be quite helpful!

Quick Fact

The water that moves through the pipes of your home often contains minerals and other substances. These substances may react to form solid precipitates. Those precipitates can settle in the pipes and clog them.

NOTES
OBJECTIVES

- Define atoms and describe the parts of an atom.
- Distinguish between elements, compounds, and molecules.
- Identify and describe ions and isotopes.

ATOMS

All matter is made up of basic elements. Elements are known as the building blocks of matter and cannot be broken down chemically into simpler substances. The elemental form of a substance is made up of only one type of atom.

**Atom**: the fundamental unit of an element. It is the smallest particle of an element that retains the element’s chemical properties. For example, a scientist cuts a piece of aluminum down until it can’t be divided anymore. Even though the piece is extremely tiny, it is still aluminum. It is an atom of aluminum.

Scientists did not always know about atoms. Today, scientists know that atoms are not the smallest units of matter and that they are made up of even smaller parts—protons, neutrons, and electrons.

- **Protons** and **neutrons** are located in the center of the atom. Together they make up the nucleus.
- **Electrons** are located somewhere in the space outside the nucleus. Some images show the electron as a small particle following a well-defined path, or orbit, around the nucleus. However, this is misleading. Electrons actually move around the nucleus in cloud-like regions. Therefore, these regions are called electron clouds (see the subsection on Electron Configuration).
  - Electrons have a mass that is 1,836 times lighter than protons and neutrons. This means that 1 proton is almost 2,000 times heavier than an electron! This difference in mass would be similar to comparing the mass of a house cat to the mass of a school bus.

Protons, neutrons, and electrons each have a different charge:

- A **proton** has a positive (+) charge
- A **neutron** does not have electric charge (0)
- An **electron** has a negative (-) charge

Atoms are **electrically neutral** when they have the same number of protons and electrons. If atoms do not have the same number of protons and electrons, they are called **ions**.

**EXAMPLE:**

The atom in the image above is electrically neutral because it has 1 proton (+), 1 neutron (0), and 1 electron (-). You can see this by adding up all the charges:

\[1(\text{proton }+) + 1(\text{neutron }0) + 1(\text{electron }-) = +1 + 0 + -1 = 0\]
HISTORY: **ELEMENTS AND ATOMS**

In the 5th century B.C., scientists presented different views of what makes up matter.

Leucippus was an ancient Greek philosopher. He is given credit for helping to bring about the theory of atoms. We know very little about his life and work. However, we do know more about one of his students, Democritus. Democritus presented the theory that all matter was made up of smaller, indivisible building blocks. He called these fundamental units of matter "atomos," meaning “cannot be divided.”

Around the same time, another view of matter existed. The Greek philosopher Empedocles taught that all matter was made of four basic substances: earth, air, water, and fire. He said these four substances are mixed together in different combinations to make up all other things.

About 100 years later (4th century B.C.), the famous ancient Greek philosopher Aristotle gave his views. He related Empedocles’ four basic substances to “blendings” of properties: coldness, hotness, dryness, and moistness. This belief is an example of a theory later proven to be incorrect. However, people believed Aristotle’s views at the time.

Aristotle did not accept the theory of atoms. Because of his fame, the atomic concept was not explored any more until about 2,000 years after it was first presented. (This shows how important it is to test ideas instead of just believing someone because they are famous!)

Then in 1661 A.D., modern chemistry began to emerge. At that time, Robert Boyle wrote what may be considered the first chemistry textbook, *The Sceptical Chymist*. His book rejected Aristotle's views and gave the first modern definition of elements.

---

HISTORY: **ERNEST RUTHERFORD** (1871–1937)

Ernest Rutherford developed a nuclear theory of the atom. His theory is known as the Rutherford atomic model.

- **Rutherford atomic model**: an atomic model that describes the atom as having a tiny, dense, positively-charged core. This core was called the nucleus. The nucleus was believed to contain nearly all of the atom’s mass. The light negative parts of the atom were called electrons. The electrons were believed to travel around the nucleus. The electrons’ movement was thought to be similar to planets revolving around the sun.

The Rutherford atomic model is also called the nuclear atom or the planetary model of the atom.

Like other scientists of his time, Rutherford conducted studies on radioactivity. He was the first to use the terms alpha, beta, and gamma to talk about radioactivity (see the Radioactivity & Nuclear Reactions section from *Chemistry Concepts in Action*).
Through advances in science and technology, scientists have been able to study atoms using a particle accelerator (atom smasher!). Two types of particle accelerators are cyclotrons and synchrotrons.

- In these accelerators, particles can move at such high speeds that the atom can break apart when it hits something.
- Particle accelerators have led to the discovery of more than 100 different subatomic particles, including quarks. **Quarks** are super-tiny particles that make up protons and neutrons.
  - There are six different types of quarks.
  - The most common types are “up” and “down” quarks. Up quarks have a charge of $\frac{2}{3}$. Down quarks have a charge of $\frac{1}{3}$.
    - A proton contains two up quarks and one down quark. Therefore, protons have a total charge of $+1$.
    - A neutron is made of two down quarks and one up quark. Therefore, neutrons have a charge of $0$.

**MOLECULES**

Well, now that we’ve broken things down, let’s build them back up! When two or more atoms interact with one another, they may form a larger unit called a molecule.

**Molecule**: the smallest particle of an element or compound that keeps the chemical properties of that element or compound.

- A molecule consists of atoms held together by chemical bonds.

**EXAMPLE:**

A water molecule is made up of two hydrogen (H) atoms and one oxygen (O) atom. This combination gives a water molecule the chemical formula $H_2O$.

A single molecule is extremely small and cannot be seen by the naked eye. While you can see a tiny drop of water, that drop contains lots and lots ... and lots of water molecules!
Elements

Each chemical element has a different atomic number. Atomic numbers are used to identify elements.

Atomic number: the number of protons in an atom’s nucleus.

**EXAMPLE:**

Hydrogen has the lowest atomic number. Its atomic number is one. This means it only has one proton in its nucleus.

Mass number (atomic mass number): the number of protons plus the number of neutrons in an atom’s nucleus.

- **Isotopes** are atoms that have the same atomic number but a different number of neutrons in the nucleus.
- The mass number for each isotope of an element is different (see the next page for the subsection on Isotopes).

Ions

The number of protons in an atom never changes. However, some atoms can either gain or lose electrons.

- Remember, protons have a positive charge. Electrons have a negative charge. Therefore, when the number of protons in an atom equals the number of electrons, the atom has no charge. Atoms with no positive or negative charge are electrically neutral.

- **Ion**: an atom or molecule that has lost or gained one or more of its outer electrons. As a result, ions have a positive or negative electric charge.
  - **Anions** are negatively-charged ions. When an atom gains electrons, the number of negatively-charged electrons is greater than the number of positively-charged protons. Therefore, the atom becomes negatively charged.
  - **Cations** are positively-charged ions. When an atom loses electrons, the atom becomes positively charged.

- Because ionizations (forming of ions) happen when electrons are gained or lost, the number of protons and neutrons of an ion does not change. Therefore, the atomic number and atomic mass number of each ion stay the same.
The image below shows three forms of hydrogen: the electrically neutral atom and two ions.*

*In the atom images above, the electron cloud, as shown in the image on page 48, has been removed for easier visualization.

**ISOTOPES**

Atoms of the same element can have different numbers of neutrons. Remember, the number of protons is the same for all atoms of the same element.

**Isotopes**: atoms of the same element with different numbers of neutrons.

**EXAMPLE:**

The most common isotope of hydrogen has no neutrons. A hydrogen isotope with one neutron is called deuterium. A hydrogen isotope with two neutrons is called tritium. The image below illustrates these isotopes of hydrogen:*

*In the atom images above, the electron cloud, as shown in the image on page 48, has been removed for easier visualization.
Hydrogen gets its name from the Greek words “hydro” (water) and “genus” (forming). It was given this name because hydrogen is a component of water. When hydrogen burns in air, it combines with oxygen to form water.

**Characteristics:**

- Is the lightest and most abundant element in the universe.
  - Is estimated to make up more than 90% of all atoms (approximately 75% of the mass of the universe).
  - Is the primary component of Jupiter and the other giant gas planets.
- Hydrogen gas (H₂) is a colorless and odorless. It is also highly flammable. (This means that it combines with oxygen to form water very easily. As a result, the reaction releases large amounts of energy.)
- Has three common isotopes:
  1. Protium is the most common isotope of hydrogen. It has one proton and no neutrons.
  2. Deuterium has one proton and one neutron.
  3. Tritium has one proton and two neutrons and is radioactive. (Tritium is produced in nuclear reactors and was used in the hydrogen bomb.)

Hydrogen is also a fuel for the stars. How? Hydrogen is a part of a nuclear process called fusion (see the Radioactivity & Nuclear Reactions section from Chemistry Concepts in Action). This process releases much, much more energy than combustion. Therefore, it allows stars to shine for billions of years.

**Quick Fact**

Our sun uses protium as the fuel for fusion reactions. On the earth, scientists are trying to build fusion reactors. These reactors would use deuterium and tritium as their fuel. The isotopes of deuterium and tritium are easier to fuse, which would make the fusion reactors easier to build.

**NOTES**
HISTORY: **HENRY CAVENDISH (1731-1810)**

Henry Cavendish was an English chemist and physicist. He realized that hydrogen gas is a distinct substance. Other scientists had produced hydrogen before, but Cavendish realized that hydrogen gas is different from air. He also showed that burning hydrogen produced water.

- Antoine Lavoisier built on Cavendish’s research and gave hydrogen its name. Lavoisier also suggested that when hydrogen was burned, it was actually combining with something. He soon figured out that hydrogen was combining with oxygen to make water.

Relative atomic mass (atomic weight): the “weighted” average mass of all of an element’s isotopes.

- The word “weighted” is important because the relative atomic mass of an element takes into account how often each isotope of an element is found in nature.

- This weighted calculation is why an element’s relative atomic mass is not a whole number.

**EXAMPLE:**

Chlorine has two primary and stable isotopes: chlorine-35 and chlorine-37. Chlorine is found in nature as chlorine-35 about 75 percent of the time. This means that 75 out of every 100 chlorine atoms is chlorine-35. Reducing the fraction, three out of every four chlorine atoms is chlorine-35. Chlorine is found in nature as chlorine-37 about 25 percent of the time. This means that one out of every four chlorine atoms is chlorine-37. Therefore, the relative atomic mass of chlorine is:

\[
\left( \frac{75\%}{100\%} \right) \times 35 \ + \ \left( \frac{25\%}{100\%} \right) \times 37 = 35.5 \text{ amu (atomic mass units)}
\]

or

\[
\left( \frac{3}{4} \right) \times 35 \ + \ \left( \frac{1}{4} \right) \times 37 = 35.5 \text{ amu (atomic mass units)}
\]
HISTORY: SCALE OF ATOMIC WEIGHTS

John Dalton was the first scientist to propose that atoms had weight. He created a scale of atomic weights for elements. He chose the lightest element, hydrogen, as his reference. He gave hydrogen a value of one. He gave all other elements higher values depending on how much heavier their atoms were compared to hydrogen.

Soon after, Swedish chemist Jöns Jakob Berzelius suggested that oxygen should be the standard reference instead of hydrogen. Hydrogen is so light that it was difficult to analyze. Berzelius believed that it made more sense to compare atoms of other elements to a heavier standard. His resulting table of atomic weights was very similar to the one used today.

Until 1960, atomic weights were expressed on a scale with oxygen as the reference. On this scale, oxygen was assumed to have 16 mass units. In 1961, a new unified scale was developed. It was based on a value of 12 atomic mass units (amu) for the carbon-12 isotope.

Quick Fact

Most atoms of carbon have 6 protons and 6 neutrons in their nucleus. Therefore, this isotope has a mass number of 12 and is called carbon-12. Carbon-12 is the most common isotope of carbon. It is the electrically neutral carbon atom. About 1 of every 100 carbon atoms has 7 neutrons and a mass number of 13 (carbon-13). The even less common carbon-14 isotope is radioactive and has 8 neutrons.

NOTES
In the 1860s, Russian chemistry professor Dmitri Mendeleev collected information about each of the known elements for his book, *Principles of Chemistry*. He used the information to organize the elements in order of their atomic weight. When he did this, Mendeleev noticed certain patterns of chemical reactivity and physical properties. Based on these patterns, he grouped the elements into rows and columns. The result is what we call the periodic table (review the Periodic Table handout).*

**HISTORY: MENDELEEV’S PERIODIC TABLE**

The periodic table Mendeleev created in 1869 is very similar to the one we use today. However, Mendeleev’s table had some problems and some gaps. The missing elements were not known at that time.

When Mendeleev created his table, he did not know what atoms were made of or why they acted in certain ways. He created his periodic table before anyone knew about the structure of atoms. What makes his work even more amazing? Mendeleev was able to predict the presence and properties of several new elements. He made these predictions based on the gaps in his table.

So, what’s the big difference between Mendeleev’s table and today’s table? Today’s table is organized by increasing atomic number. Mendeleev’s used increasing atomic weight.

- At first, atomic numbers were based on an element’s position on Mendeleev’s periodic table. Therefore, the atomic numbers were based on increasing atomic weight. Because hydrogen has the lowest atomic weight, it was given the first atomic number (1). Arranging the atoms according to their weight was not quite right, though. As a result, Mendeleev’s periodic table had some problems.

- In 1914, Henry Moseley conducted experiments on elements using X-rays. As a result of these experiments, Moseley was able to relate an element’s atomic number to the charge of its nucleus. This charge represented the number of protons in the nucleus.

- Moseley showed that atomic numbers were significant! Atomic numbers could be measured through experiments. Two atoms having slightly different atomic weights but the same atomic number behaved alike.

- After Moseley’s discovery, the periodic table was reorganized. It is now organized by atomic number.

*The Periodic Table handout is available on CEF’s website at www.chemed.org. Ask your teacher or Local Challenge Organizer for more details.

**THE CORE OF CHEMISTRY, SECTION V:** The Periodic Table
In the early 1800s, Jons Jakob Berzelius created a new system for writing elements. He began using just one or two letters to represent an element. The shortened versions were called chemical symbols.

The first letter of a chemical symbol is always capitalized. If a chemical symbol has a second letter, it is written in lowercase. For example, the chemical symbol for hydrogen is H. The chemical symbol for helium is He.

### ARRANGEMENT OF ELEMENTS ON THE PERIODIC TABLE

Chemical elements are arranged into rows and columns, creating a table—the periodic table! These columns and rows are called groups and periods.

**Groups (families):** the vertical columns on the periodic table. There are 18 groups on the periodic table.

- Members of each group have the same number of electrons in their outer electron energy level or “shell” (see the subsection on Electron Configuration).
- Most reactions involve only the outer electrons. Therefore, members of the same group generally participate in the same types of reactions.
- Members of the same group usually have very similar properties.

**Periods:** the horizontal rows on the periodic table. There are 7 periods on the periodic table.

- Members of the same period do not have similar properties. As you move across the periodic table, from left to right, the properties of the elements change greatly.
- Members of the same period have the same number of electron “shells.” However, they differ in how they are filled. As explained on page 72, these “shells” represent the energy level of the electrons.
- Some periods on the table are much longer than others. Look at the sixth and seventh periods. Notice something different? These periods are very long. As a result, some elements from these periods were removed from the main table. They were placed below the table in separate rows. The elements from atomic number 57 to 71 (the lanthanide series) and the elements from atomic number 89 to 103 (the actinide series) make up these rows.
Scientists often classify elements as either metals or nonmetals.

- Metals are found mainly on the left side of the periodic table.
  - They are generally solid at a normal room temperature of about 75 °F and have a shiny appearance. (For information on other metal properties, see the subsection on Types of Chemical Bonds from Chemistry Connections. These properties include luster, conductivity, malleability, and ductility.)
  - Metals normally give up electrons in a chemical reaction.

- Nonmetals are usually on the right side of the periodic table.
  - They are generally gases or solids at a normal room temperature.
  - Most solid nonmetals are dull and brittle. They can be broken apart easily.
  - They normally take electrons in a chemical reaction.

- Semi-metals (metalloids) are located between metals and nonmetals on the periodic table. They fall along a zigzag line that divides metals and nonmetals.
  - Semi-metals have some properties of both metals and nonmetals.
  - All semi-metals on the periodic table are solids at a normal room temperature.
  - They include boron, silicon, arsenic, and germanium.

**ELEMENTAL GROUPS**

**GROUP 1 – ALKALI METALS** (except hydrogen)

- Are soft low-density metals.
- Have low melting points and oxidize easily. (They become dull when exposed to air.)
- Are extremely reactive and are rarely found in elemental form (as pure elements) in nature.
- Are known to react strongly with water.
- Have only one electron in their outer energy level or “shell” (see the subsection on Electron Configuration).
- Are likely to give one electron away to form a bond to reach the very stable, “filled outer shell” state.
- Form strong bonds with the halogen elements because halogens need only one electron to complete their outer “shell.”
- Include lithium, sodium, and potassium.

**Quick Fact**

There are two elements that are liquid at a normal room temperature. One is a metal and one is a nonmetal. Those elements are mercury and bromine.

**Quick Fact**

Carbon and sulfur are examples of solid nonmetals. Helium and nitrogen are examples of gaseous nonmetals.

**Quick Fact**

Even though hydrogen is at the top of group 1, it is not considered an alkali metal. Instead, hydrogen is found naturally as a diatomic gas. Therefore, hydrogen can have characteristics of two groups—one and seventeen. Some periodic tables show it that way. See if you can find one!
Sodium is found abundantly on the earth in many minerals. It is found most commonly in the mineral halite (rock salt or NaCl, sodium chloride).

- Every gallon of sea water contains about 0.25 pounds of NaCl.
- Everyday table salt is mainly made up of the compound NaCl. Most table salts are made of about 97% to 99% NaCl with the rest being small amounts of iodine and other ingredients.

**Characteristics:**
- Is a silvery metal that tarnishes quickly in air.
- Is soft and malleable.
- Is not found in nature in its pure form because it is highly reactive.
- Is an essential element for living things, including humans.
  - Helps to regulate the balance of water in the body.
  - Prolonged sweating results in sodium loss from the body.

The most important sodium compound since ancient days has been table salt. Table salt is typically used to preserve food. Another common sodium compound is sodium bicarbonate (NaHCO₃). It is commonly called baking soda because it is used in baking. It is also used in antacids to neutralize excess stomach acid and in fire extinguishers.
Potassium gets its name from the word “potash.” Potash originally referred to wood ashes. Today, potash refers to various compounds of potassium, such as potassium carbonate ($K_2CO_3$). In the fertilizer industry, potassium oxide is called potash. Potassium hydroxide is often called caustic potash.

**Characteristics:**

- Is a soft silvery metal in elemental form.
- Has a lower density than water.
- Reacts with water to produce KOH, hydrogen gas, and heat, which usually ignites the hydrogen.

Potassium is an essential element for human health. Like sodium, it helps to keep a normal water balance between the cells and body fluids. Potassium can be obtained by eating vegetables and fruits. Foods high in potassium include bananas, cantaloupes, and oranges.

Potassium is also required for plant growth. It is found in most soils and is commonly used in fertilizers.

Just as the carbon-14 isotope is used to “carbon date” organic materials, potassium-40 is used to date rocks (see the Radioactivity & Nuclear Reactions section from Chemistry Concepts in Action).

**Quick Fact**

Potassium is an electrolyte, a substance that conducts electricity in the human body. Electrolytes easily separate into ions in a solution, which enables them to conduct electricity. Other electrolytes in the body include sodium, chloride, calcium, and magnesium.

**GROUP 2 – ALKALINE EARTH METALS**

- Are harder and denser than alkali metals.
- Are gray- or silver-colored metals with high melting points.
- Are very reactive metals (although less reactive than alkali metals).
- Are found in the earth’s crust but not in elemental form because of their reactivity. They are found in many rocks on the earth.
- Have two electrons in their outer energy level, which they tend to give away.
- Include beryllium and magnesium.

**Quick Fact**

When combining with nonmetals, the reactivity of an alkali or alkaline earth metal increases with its atomic number. Therefore, lithium is the least reactive of the alkali metals. Beryllium is the least reactive of the alkaline earth metals.
The name magnesium comes from the Latin word “magnesia.” It was named after an ore found in the area of Magnesia in Thessaly, Greece.

**Characteristics:**
- Is a grayish-white metal.
- Is essential for human health.
  - Helps to transmit nerve impulses and cause muscles to contract.
  - Is found in our bones (about 50% of the magnesium in the human body is found in bones).
- Is the lightest industrial metal, with a density that is about the same as man-made plastics.

When magnesium metal is placed in a flame, it produces a bright white light as it combines with oxygen in the air to form magnesium oxide. Because of this property, magnesium is commonly used in flares.

Magnesium is a component of Epsom salts (hydrated MgSO₄). Epsom salts are used to soothe aches and pains.

The name calcium comes from the Latin word “calx,” meaning lime. It is found naturally in limestone as calcium carbonate (CaCO₃). The most common natural forms of calcium carbonate are limestone, chalk, and marble. Calcium carbonate also makes up eggshells and the shells of marine animals like clams.

**Characteristics:**
- Is the 5th most abundant element in the earth’s crust.
- Is not found naturally in its elemental form.
- Is an essential component of leaves, bones and teeth, and shells.

About 99% of the calcium in the human body is stored in our bones and teeth. It helps to support bone and teeth structure. This is why people say calcium keeps your bones strong.

Calcium is a component of mortar, plaster, and cement. The Romans used it for construction. Even writings from 975 A.D. mention that plaster of paris (CaSO₄) is useful for making casts to set broken bones.
GROUPS 3–12 - TRANSITION METALS

- Have good thermal and electrical conductivity.
- Are hard metals and have very high melting points.
- Have low to moderate reactivity.
- Cannot be divided neatly into individual groups.
  - All of the transition elements have similar properties.

Most elements can only use electrons from their outermost orbital to bond with other elements (see the subsection on Electron Configuration in this portion of the Passport and the subsection on Periodic Trends from Chemistry Connections). Transition metals can use the two outermost orbitals. This chemical trait allows them to bond with many elements. It also means that transition metals do not always use the same number of outer electrons during chemical reactions. For example, during some reactions, iron may give away two electrons. In other reactions, iron may give away three electrons.

Transition metals often form colorful compounds. They also often form compounds in more than one oxidation state.

- **Oxidation state**: the charge that develops on an atom as a result of a loss or gain of electrons. (For more information on oxidation states and numbers, see the Chemical Formulas section from Chemistry Connections.)

Groups 10 and 11 contain the **precious metals**—silver, gold, palladium, and platinum.

Group 12 metals have lower melting points than the other transition metals. Mercury has the lowest melting point of all the transition metals. Its melting point is so low that it is a liquid under normal conditions.

Quick Fact

Oxidation was originally defined as the combination of oxygen with other elements or compounds. Today, the use of the term has grown. Oxidation is now often defined as the loss of at least one electron when substances react.

Quick Fact

The transition metals iron, cobalt, and nickel are the only elements known to produce a magnetic field.
Iron is one of the most abundant metals on the earth. It forms about 5.6% of the earth’s crust. The core of the earth is believed to be mostly made up of molten iron. Iron’s chemical symbol comes from the Latin word for iron, “ferrum.”

**Characteristics:**

- Is believed to exist in small amounts in many types of stars, including our sun.
- Is mainly obtained from the minerals hematite (Fe₂O₃) and magnetite (Fe₃O₄).
- Is a strongly magnetic element.
- Is an essential element for many living things, including humans.

Pure iron metal oxidizes in moist air to form rust. The chemical name for rust is iron oxide. Therefore, when iron combines with oxygen in the air, iron oxide is formed. The chemical formula for iron oxide is Fe₂O₃. (Notice that in mineral form, it is called hematite.)

Alloying iron with carbon creates steel. (Adding other metals, such as nickel and chromium, changes the properties of the steel. Doing that gives the steel greater strength, resistance to corrosion, less brittleness, and other favorable characteristics.)

**Quick Fact**

Iron ores are rocks and minerals that contain iron compounds. They vary in color from dark gray to rusty red. Pure metal iron can be extracted from these ores.
Silver
Atomic #47

The chemical symbol for silver comes from the Latin word for silver, “argentum.” Silver has been used since ancient times. Today, it is used in many countries to make coins.

Characteristics:

- Has a bright white luster.
- Is a very ductile and malleable metal.
- Has the highest thermal and electrical conductivity of all metals.

Silver is stable in pure air and water. However, it undergoes a chemical reaction when exposed to air containing sulfur compounds. The reaction produces silver sulfide, a black substance known as tarnish.

Silver can be used to make high-quality mirrors. Silver has the ability to reflect almost 100% of the light that hits it. However, silver loses much of this ability when it becomes tarnished.

Sterling silver is an alloy of 92.5% silver and 7.5% copper. It is harder than pure silver and has a lower melting point. For these reasons, it is often used in jewelry and silverware.

Zinc
Atomic #30

Pure metal zinc is thought to have been produced in India around the 1400s. In 1746, it was rediscovered in Europe by Andreas Marggraf. Zinc compounds were used long before that time. Zinc was used in the production of brass by the ancient Romans as early as 500 B.C.

Characteristics:

- Bluish-white shiny metal.
- Used in dry cell batteries.
- Used to form alloys with copper, nickel, aluminum, and lead.

Today, zinc is mainly used in a process called galvanization. In this process, a layer of zinc is deposited on the iron. In the presence of air, the zinc oxidizes. When this happens, a coat of Zn(OH)$_2$CO$_3$ forms. This coating protects the iron and prevents further corrosion.

Zinc oxide (ZnO) is used as a pigment in paints and is found in some cosmetics and ointments. In addition, zinc is often found as a sulfide compound. Zinc sulfide (ZnS) is used in fluorescent lights, x-rays, and TV screens.
Gold is an attractive and valuable metal. It is used as a money standard in many countries. Gold is formed into bars and ingots for accounting and storage purposes. Its chemical symbol comes from the Latin word for gold, “aurum.”

Characteristics:

- Is a very ductile and malleable metal. Gold and silver are more ductile and malleable than almost all other metals.
- Is normally yellow in color but may look black, purple, or red when finely divided.
- Is an excellent conductor of heat and electricity.
- Reflects infrared radiation well (see the subsection on Electromagnetic Waves from Chemistry Concepts in Action).
  - May be formed into a foil to help shield spacecrafts and skyscrapers from the sun’s heat.

Pure gold is very soft, so it generally needs to be alloyed with other metals to make it stronger. The purity of gold is measured by a unit called a carat. Gold that is 100% pure is called “24 carat” gold. Gold that is 14 carat is 14 parts gold and 10 parts alloyed metal.
GROUP 17 – HALOGENS

- Are nonmetal elements.
- Exist as diatomic molecules at a normal room temperature—F₂, Cl₂.
- Are highly reactive and are not found naturally in pure form on the earth.
- Need only a single electron to complete their outer energy level (shell).
  - Often bond with alkali metals.
- Include fluorine, chlorine, and bromine.

At a normal room temperature, the halogen group includes elements that occur in solid, liquid, and gaseous states. Iodine is a solid. Bromine is a liquid. Fluorine is a gas.

Halogens react with metals to form salts. Halogen salts include sodium chloride (NaCl) and calcium chloride (CaCl₂).

Mercury is commonly known as “quicksilver.” It gets its chemical symbol from the Latinized Greek name “hydragryum,” meaning liquid silver.

**Characteristics:**

- Is the only metal element that is liquid at room temperature (with room temperature approximately 75 °F).
- Has very high surface tension.
- Is a very good conductor of electricity but not of heat.
- Is found in the red mineral, mercury (II) sulfide (HgS), commonly called cinnabar.

In the past, mercury was commonly used in thermometers, barometers, and laboratory vacuum pumps. Today, mercury use is limited. Mercury and many of its compounds are toxic to humans. Mercury exposure can cause damage to the central nervous system and to the immune system.

Mercury alloys are called amalgams. Amalgams are alloys of mercury with at least one other metal, usually gold, silver, tin, or copper. Silver amalgams are used in dentistry. They often contain small amounts of other metals like tin and copper. These dental amalgams were used for years to fill tooth cavities. They are strong and durable, but soft enough to fit the size and shape of the cavity. However, most dentists now use tooth-colored fillings instead of amalgams.
Fluorine is so reactive, it is difficult to separate from compounds. It was finally separated in 1886 by French chemist Ferdinand Frederic Henri Moissan. For nearly 75 years before, many other scientists tried but were not successful.

**Characteristics:**

- Is the most electronegative element (see the subsection on Periodic Trends from Chemistry Connections).
- Is the most reactive element, reacting with nearly all organic and inorganic substances.
- Is a pale yellow-green color and is highly corrosive in gaseous form.

In the late 1600s, minerals containing fluorine were used to etch glass. Eventually, scientists figured out what substance was making that work. The substance attacking the glass was hydrogen fluoride (HF). A lot of accidents occurred during early work with HF and fluorine because of their reactivity.

- When HF is dissolved in water, it is known as hydrofluoric acid. It is a very corrosive and dangerous acid.

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**Quick Fact**

Fluorine compounds are added to toothpaste to help prevent tooth decay.

**Quick Fact**

Fluorine’s reactivity makes it difficult to store. It attacks glass and causes most metals to burst into flames.

**Quick Fact**

Fluorine is so highly reactive that it forms compounds with krypton, xenon, and radon—elements that were considered to be unreactive for many years.
The name chlorine comes from the Greek word “chloros” meaning “pale green.” In 1774, Karl Wilhelm Scheele first produced the gas. However, he believed the gas he produced was a compound that contained oxygen. He was incorrect. In 1811, Sir Humphry Davy realized the gas was actually a new element.

Characteristics:

• Is a very reactive halogen that combines directly with almost all elements.

• Is found abundantly in the form of NaCl.

• Is used commercially as a bleaching substance and a disinfectant.

As a gas, chlorine has a yellowish-green color. It has a high density (for a gas) of 0.0032 g/mL. Its density is approximately 2.5 times greater than air. As a result, chlorine gas generally remains close to the ground unless there is significant air movement. The gas also has a sharp odor. It is extremely irritating to the respiratory system and was used for chemical warfare during World War I.

Chlorine is used to disinfect or “chlorinate” water. The amount of chlorine needed to kill harmful bacteria and other microorganisms depends on what is in the water. Adding chlorine to water can make it safer to drink. This process is used all across the world. Today, most water supplies are chlorinated. However, the proper amount of chlorine must be used.

It is also used in many other everyday products. These products include paper products, textiles, petroleum products, medicines, disinfectants, pesticides, food, paints, and plastics.

GROUP 18 – NOBLE GASES (INERT GASES)

• Are all colorless, odorless gases under normal conditions.

• Have low boiling points.

• Have almost no reactivity. (The term “inert” means inactive.)

• Have complete outer electron energy levels, creating a very stable state (see the subsection on Electron Configuration).

• Do not tend to form chemical bonds and are unlikely to gain or lose electrons.

• Include helium, neon, and argon.
Noble gases are commonly used in lighting. Argon is used in common incandescent light bulbs. Neon is often used in lighted restaurant and advertising signs. Therefore, these signs are called “neon” signs. The other noble gases are used in these signs as well. The signs are made of glass tubes containing the noble gases. When an electric current is passed through the tube, the noble gases will glow with bright colors. Neon creates a reddish-orange color. Argon produces a pale purple color. Other colors are created by mixing the gases together or mixing them with other elements.

Helium was discovered when Pierre Janssen and Norman Lockyer noticed something strange about the light from the sun. Lockyer hypothesized that it was an unknown element. He named the new element helium. Helium gets its name from the Greek root “helios” meaning “sun.”

**Characteristics:**

- Is the lightest of the noble gases.
- Is the second most abundant element in the universe.
- Has the lowest boiling point of any element.
- Used for inflating lighter-than-air balloons because it is less dense than oxygen or nitrogen.
  - Unlike hydrogen, helium is not combustible.
  - French physicist Jacques Charles is credited for being the first to use helium in a passenger balloon.

Helium also has the lowest freezing point of any element. It is the only element that cannot be changed from a liquid to a solid by just lowering the temperature. It will remain a liquid even as its temperature gets close to absolute zero at standard pressure. However, helium can be changed into its solid form by increasing the pressure and decreasing the temperature.

**Quick Fact**

Why does helium end with “um” rather than “on” like the other noble gases? It was because of a guess that the new element was a metal. At the time, names of metal elements generally ended with “um”—potassium, lithium, etc. So, if helium had been discovered first on the earth rather than in the sun, it might have been called “helion”!
Argon gets its name from the Greek word “argos” meaning “inactive.”

**Characteristics:**

- Is colorless and odorless as a gas and a liquid.
- Makes up a little less than 1% of the earth’s atmosphere by volume.
- Is used in incandescent light bulbs.
  - It prevents oxygen from corroding the hot wire filament inside the bulb.

Argon-40 is the most abundant isotope of argon. Argon-40 is produced by the decay of potassium-40. Scientists can compare the proportion of K-40 to Ar-40 in a rock or mineral sample to figure out its age. This radioactive dating process is known as potassium-argon dating. Geologists have used this method to date rocks as old as 4 billion years. In addition, this method is also used to figure out the age of ancient human artifacts.

### LANTHANIDE AND ACTINIDE SERIES

Elements located in the two rows at the bottom of the periodic table are called the *inner transition metals*. They are not considered to be a part of any of the 18 groups.

**Lanthanide series (or lanthanoid series):** the inner transition metals from period 6. They are named after the first element in the series, lanthanum.

- Are shiny, silvery-white metals.
- Are chemically similar to each other. Their properties differ only a little because of their different atomic numbers.
  - Have high melting and boiling points.
  - Most oxidize quickly in air to form a tarnish.
  - React with water to release hydrogen gas.

Lanthanides are found naturally on the earth. They were originally classified as rare earth metals, but now scientists know that most lanthanides can be found in large quantities in the earth’s crust. Most of the lanthanides occur together in nature. They are also difficult to separate from each other.

Quick Fact

The wire filament in most incandescent light bulbs is made of tungsten because the metal has a very high melting point.

Quick Fact

Scandium and yttrium have properties similar to the lanthanides. Therefore, they are sometimes treated as lanthanides.
Many lanthanides are used as phosphors. A phosphor is a chemical substance that emits light when energized by electrons. Most lanthanides emit colored light when they are bombarded by a beam of electrons. As a result, they are used in fluorescent light bulbs and TV sets. They are also often used in lasers and sunglass lenses.

Some lanthanide compounds are used in catalysts. They help to speed up the process by which crude oil is changed into gasoline and other products. Lanthanide compounds are also used in searchlights and magnets.

**Actinide series (or actinoid series):** the inner transition metals from period 7. They are named after the first element in the series, actinium.

- Are hard metals that tarnish in air.
- Are all radioactive elements and are used in the nuclear energy field.
  - Studies on actinide properties have been difficult because of their radioactive instability.

**ELECTRON CONFIGURATION**

How does an element get its chemical properties? They mainly come from the atoms’ electrons. All electrons are the same, but they aren’t all found in the same places in the atom. **Electron configuration** is the term for how electrons are arranged within an atom.

Because scientists are not able to observe all phenomena and scientific processes, they use models. A **model** is an image, picture, diagram, mathematical equation, or other representation of a phenomena or process. It is important to remember that models are used to help with our understanding of things we may not be able to observe easily. Therefore, they may not be exact. As mentioned earlier, scientists have developed different models of the atom over the years. These models have helped scientists to build a better understanding of atoms and of science in general.

For a long time, scientists thought electrons traveled around the nucleus in simple orbits. (They pictured it the same as the way the planets move around the sun.) We now know that this is not correct. Electrons move around the atom, but they don’t move in simple circular orbits. They are actually found in cloud-like zones around the nucleus. The constant random and rapid movement of the electrons makes it very hard to predict their location and speed. Therefore, they are “somewhere in the cloud.”

You can think of it like an airplane that flies through a cloud. Even if you watched carefully as the plane entered the cloud, the pilot could turn the airplane in another direction once inside. You would have a very hard time knowing where the plane was. However, you could use radar to locate the approximate location of the plane.

**Quick Fact**

Only uranium, thorium, protactinium, and very small amounts of actinium and plutonium are found naturally on the earth. The other actinides are produced artificially in nuclear reactors and particle accelerators. Most plutonium is produced artificially, as well.
Scientists of the 20th century studied how light interacts with the electrons. This helped them figure out more about the location of electrons in atoms. However, this information is not perfect.

**Heisenberg's uncertainty principle** states:

- The more accurately we can determine the position of an electron, the less accurately we can determine the momentum of the electron at that point in time.
- Likewise, the more accurately we can determine the momentum of an electron, the less accurately we can determine the position of the electron at that point in time.

Simply stated, Heisenberg’s uncertainty principle tells us that it is impossible to know both the exact position and the exact velocity of a particle at the same time.

An orbital is a specific area outside of the nucleus where an electron is likely to be found. (Be careful not to confuse cloud-like orbitals with circular orbits.) Different orbitals are grouped according to their shapes and are identified by the letters s, p, d, and f. The letters correspond to the general shape of the orbital cloud. For example, an s orbital is spherical. It looks a little bit like a cotton ball. The p orbitals look like two touching cotton balls. The d and f orbitals have more complicated shapes.

To get an idea of an electron’s location, the first thing to know is its **principle quantum number**. This number is simply a whole number (1, 2, 3 …) that gives us an idea of the size of the orbital. Therefore, it also describes the overall energy of the electron. A level 3 electron has more energy than a level 2 electron.

In general, electrons with lots of energy tend to be farther from the center of the atom. This also means that those orbitals are usually larger.

**EXAMPLE:**

A 3s orbital is larger than a 1s orbital. However, both are s orbitals, so they have the same spherical shape.

An electron with more energy can occupy more of the different types of orbitals. (You can think of electrons like people. The more energy a person has, the more places he/she will go. You will not find a couch potato on the top of Mount Everest.)

**EXAMPLE:**

An energy level 1 electron can be found in only one type of orbital. It would be found in a simple s orbital. An energy level 3 electron can find its way into an s orbital, one of three possible p orbitals, or one of five possible d orbitals! Therefore, a level 3 electron can “choose” from nine different orbitals.
Each orbital can hold up to two electrons. Based on the example above, we know that an atom cannot have more than 18 electrons with energy level 3. (How do we get 18? There are nine orbitals that hold two electrons each.) The example also tells us that there are different numbers of each type of orbital.

- The s type has one orbital, which can hold up to two electrons.
- The p type has three orbitals. Each of those orbitals can hold two electrons, for a total of six electrons.
- The d type has five orbitals. Each of those orbitals can hold two electrons, for a possible total of ten electrons.
- The f type has seven orbitals. Each of those orbitals can hold two electrons, for a total of up to fourteen electrons.

The table below breaks down the amount of electrons that different types of sublevels or subshells can “hold”:

<table>
<thead>
<tr>
<th>Subshell Type</th>
<th>Number of Orbitals</th>
<th>Maximum Number of Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>s</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>p</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>d</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>f</td>
<td>7</td>
<td>14</td>
</tr>
</tbody>
</table>

These orbitals and the electron energy levels are filled in a specific order, as shown in the diagram below:

**Quick Fact**
The term “sublevel” can also be used instead of subshell. For example, we can say that “lithium has electrons in the 1s and 2s sublevels.” Therefore, we know that its electrons occupy the 1s and 2s subshells.

As shown above, the order for filling in the orbitals and energy levels is: 1s, 2s, 2p, 3s, 3p, 3d, 4s, 4p, 5s, 5p, 6s, 6p, 7s, 7p, etc.

Start at the top (1s). Begin at the base of each arrow and follow it all the way to the point. As you go, fill in the orbitals and energy levels that the arrow passes through.

**Quick Fact**
Notice that electrons will go into a 4s orbital before they go into a 3d orbital. This may make you think that the 3d state has more energy than the 4s state. But wait, the 3d state has a lower principal quantum number! There is no simple answer here. However, it has to do with how an electron interacts with all the other electrons already in the atom. (Again, you can think of this in terms of people. A mountain climber might have the energy needed to climb Mount Everest. However, he/she may stay at the base camp if there are already too many people at the top.)
Scientists use a certain format to write an atom’s electron configuration. The electron configuration below represents the element helium.

\[ 1s^2 \]

- The first number is the principle quantum number. Again, it is the electron’s energy level. In this case, the “1” represents the first energy level. It tells us that the electrons of helium occupy the first energy level of the atom.
- The letter refers to the type of orbital. In this case, the “s” tells us that the helium atom’s two electrons occupy an "s" orbital.
- The superscript number refers to the total number of electrons in that orbital type. In this case, the “2” tells us that there are two electrons in the “s” orbital at the “1” energy level.

As the image of the lithium atom shows, the first two orbitals are s orbitals. Therefore, they have a spherical shape. Also notice that the second energy level orbital is farther from the nucleus.

The electron configuration for lithium is: \( 1s^22s^1 \).

Notice that the last (and only!) energy level where helium electrons can be found is the first energy level \((1)\). For lithium, its last electron can be found in the second energy level (the 2s sublevel). Helium is in the first row of the periodic table. Lithium is in the second row.

Look up the electron configuration for other elements. Then, look at their location on the periodic table. Do you see the pattern?

**NOTES**
SECTION VI: LABORATORY EQUIPMENT

OBJECTIVES

- Identify various types of laboratory equipment.
- Describe how certain laboratory equipment is used to conduct experiments.

BASIC EQUIPMENT

Chemists use many different types of equipment in the laboratory to perform their experiments. This equipment includes glassware, measuring tools, and other specialized instruments. The following are some examples of common laboratory equipment:

**Beaker**: a wide container with a flat bottom made of glass or plastic.
- A beaker is a simple container used to mix, heat, or simply hold liquids (and sometimes solids).
- If the beaker is **graduated**, it can give approximate measurements of liquid volumes. The term “graduated” means it is marked with or divided into measurements.
- The top rim of the beaker usually has a **lip**. The lip is a curved indentation that allows liquids to be easily poured from the beaker.

**Flask**: a glass container with a thin “neck” that widens to a flat or rounded base. It can be used to measure, heat, or store liquids.
- The neck of the flask allows scientists to either attach a clamp to it or place a stopper in it.
- **Erlenmeyer flask**: a flask with a cone-shaped base. It is used most often to hold liquids during a filtration or titration process (see page 78).
  - A liquid contained in an Erlenmeyer flask will heat quickly. This is because the wide surface area of the flask’s bottom provides a larger surface that can collect the heat.
  - Erlenmeyer flasks are very stable. Their shape makes them unlikely to tip. Scientists can also swirl a liquid inside with little risk of the liquid spilling out of the flask.
• **Florence flask (boiling flask):** a round (spherical) flask that may have a rounded or flat-bottomed base.
  
  – A Florence flask with a flat bottom can sit upright on a flat surface. A Florence flask with a round bottom needs to be held or supported so it does not tip over.
  
  – A liquid contained in a Florence flask will heat evenly. This occurs because the round shape spreads the heat around the flask.
  
  – Florence flasks are generally stronger than other flasks. They are often used to boil liquids for distillation processes. Therefore, they must be able to withstand extreme temperature changes. (For information on distillation, see the Laboratory Separations section from *Chemistry Concepts in Action*.)

• **Volumetric flask:** a flask with a pear-shaped base and a long neck. The neck of a volumetric flask is usually fitted with a stopper.
  
  – Each volumetric flask is marked to hold a specific volume, such as 50 mL, 100 mL, or 250 mL. A single line around the long neck marks the point to where the flask should be filled.
  
  – Volumetric flasks are used to accurately measure liquids to a fixed volume. Scientists can also make up solutions of fixed volumes in the flasks.

*Test tube:* a small cylindrical glass tube that has a rounded, u-shaped bottom.

• Test tubes are used to hold or heat small amounts of a substance during laboratory experiments.

• A stopper may be placed in the top opening of a test tube. This allows scientists to temporarily store the substance inside the test tube.

• Test tubes are usually held upright using clamps or special test tube holders. They may also be placed upright in special racks.

### MEASURING LIQUID VOLUMES

**Graduated cylinder:** a tall, cylindrical container with a wide, flat base that is used to measure the volume of a liquid. The top of the cylinder is open and usually has a small curved lip. This allows you to easily pour liquids from the cylinder.

• It was named a “graduated” cylinder because it has markings along the side. These markings indicate how much volume is being measured.

• Graduated cylinders are made in many different sizes, generally ranging from 10 mL to 2,000 mL.
When looking at a liquid in a graduated cylinder, you will most likely notice a slight curve at the liquid’s surface. (This curve does not appear in some plastic graduated cylinders.) This concave (inward) curve at the liquid’s surface is called the meniscus.

- A meniscus is created when the liquid’s particles are attracted more to the container than they are to each other.
- To figure out how much liquid is in a graduated cylinder, scientists take the measure from the bottom of the meniscus (see the image to the upper right). This measurement is the volume of the liquid.
- Remember to read the measurement at eye level. You should make sure you read all measurements at eye level to get the most accurate reading.

**Think About It...**

Why should you take all measurements at eye level? Let’s experiment! Pick some measurement device for your test—a graduated cylinder, a scale, or an analog clock (not digital). Then, have you and your friends stand in different places around the device (above, below, far to the right or left, etc.) and record your measurements. What do you notice?

**HISTORY: DISPLACEMENT**

Over 2,000 years ago, ancient Greek mathematician Archimedes made a very useful measurement observation. As legend has it, Archimedes noticed that when he stepped into a bathtub of water, the water level rose. When he sat down in the water, it rose even higher. Archimedes had uncovered the concept of displacement.

**Displacement** occurs when one substance takes the place of another. Therefore, Archimedes observed his body taking the place of the water. The water rose in the tub as it was pushed out of the way by his body.

The concept of displacement can be used to measure the volume of solids with irregular shapes. When an object is placed under water, the volume of the water that the object displaces is equal to the volume of the object. For this to be true, the object must be completely under the water.

Scientists often use graduated cylinders to measure the volume of irregularly shaped solids. First, they add a certain amount of water to a graduated cylinder. (If the solid reacts with water, they may need to choose another liquid for the measurement.) Then, they carefully drop the solid into the cylinder along the side. After the solid is submerged, they take the new measurement. Finally, they subtract the original volume from the new volume to determine the volume of the solid.

For example, you fill a graduated cylinder with 50 mL of water. Then, you drop a small object into the water. You take a new measurement at the liquid’s meniscus and get a measure of 60 mL. This means that the solid has a volume of 10 mL.

Other graduated lab devices can be used as well. Beakers are sometimes used for larger objects. However, the measurement may not be accurate.
Buret (or burette): a long glass cylinder used to measure and dispense a specific volume of liquid very accurately. The cylinder is open at the top end. The bottom end comes together into a tip. The liquid flows or drips out of the buret from this tip. A stopcock valve is attached to the bottom end, just above the tip.

- The stopcock valve controls the amount of liquid that flows from the buret. When it is opened, the liquid flows or drips out of the tip. When it is closed, the liquid is held in the buret.

- Burets are generally used for titrations (see the Laboratory Analysis section from Chemistry Concepts in Action).
  - During a titration, scientists place an Erlenmeyer flask directly below the tip of the buret.
  - The Erlenmeyer flask generally contains some other substance or solution.
  - The scientist then opens the buret slowly to allow some of the liquid in the buret to drip into the flask.

- Liquids in a buret should not contain bubbles. Why? Bubbles affect measurements.
  - Once a buret is filled with a liquid, you should open the stopcock valve. Let a few milliliters of the liquid flow from the buret into an empty beaker or flask.
  - After closing the stopcock valve, gently tap the sides of the buret. This action will release any remaining bubbles from the liquid.
  - Then, replace the beaker or flask with the Erlenmeyer flask that contains the solution. Now, you are ready to begin your titration.

MEASURING MASS

Mass is measured using devices known as balances. Balances measure mass by comparing an object of unknown mass to an object of known mass. This comparison is important because it makes sure that gravity does not affect the measurement.

Triple-beam balance: a device used to measure the mass of an object.

- The balance has a pan connected to three beams marked with certain measurements.

- Each beam has a different size “weight” attached to it. These “weights” are called riders. Each rider gives a measurement in grams.

- Attached to the other end of the beams is a pointer. This pointer shows when the device is balanced.

- To measure an object’s mass, the object is placed on the pan. Then, the riders are moved across the beams until the pointer shows that the riders and the object on the pan are balanced. Once in balance, the locations of each rider on the beams indicate a certain measure in grams. The total sum of these measurements is equal to the mass of the object on the pan.
Many science laboratories use instruments called analytical balances or single-pan electronic balances.

- These balances measure with great precision and accuracy.
- To measure an object’s mass, the object is placed on a pan. The measurement then appears on the digital display on the front of the balance.
- The measuring pan of an analytical balance is closed inside the device. The closed area prevents dust from collecting on the pan. It also prevents air currents in the room from affecting the measurement.

Scientists need to make sure their balance is set properly before taking a measurement. If the balance is not set properly to begin with, you will not get a good measurement. Therefore, scientists often measure an empty container first and then measure the container with a substance inside. Once they have both measures, they subtract the empty container measurement from the combined measurement. The result is the measure of the substance only.

- The mass (or weight if measuring on a scale) of the empty container is called the tare (or tare weight).
- Some balances provide an option for automatically “taring” the vessel. Then, the mass or weight of the substance can be read directly on the display.

**MEASURING TEMPERATURE**

*Thermometer*: a device used to measure temperature.

- Traditional bulb thermometers measure temperature based on the expansion of a fluid.
  - Traditional bulb thermometers are thin graduated glass tubes. They have a bulb at one end that holds a fluid. As the fluid is heated, it expands. As the fluid expands, it is pushed up the tube. Because the tube is so thin, even a small increase in volume causes the fluid to rise noticeably.
  - The markings of a thermometer are generally determined based on two fixed reference points, usually the freezing point and boiling point of water.
  - The degrees of measurement depend on the temperature measurement scale being used, whether Fahrenheit, Celsius, or Kelvin.
  - These thermometers need time to react to the temperature change. Therefore, you may need to wait a few minutes to get a good temperature measurement.
Today, you are more likely to see digital or electronic thermometers. These thermometers measure temperature using thermoresistors or “thermistors.”

- **Thermistors** contain a semiconductor substance. A semiconductor is a substance that conducts an electric current well at high temperatures but not at low temperatures. Therefore, at high temperatures, their resistance is low. At low temperatures, their resistance is high.

- A microchip inside measures this resistance. Then, the microchip converts that measurement into a temperature measurement.

- That temperature measurement then appears on a digital display. (For example, many houses and other buildings have digital thermostats to control inside temperatures. These thermostats use thermistors.)

- Unlike traditional bulb thermometers, the process happens very quickly. You are able to see a temperature measurement almost immediately.

Another type of thermometer is a bimetallic strip thermometer. These thermometers measure temperature based on the expansion of metals.

- Inside these thermometers, two different metals are bonded together. Those metals will expand at different rates when heated. As a result, the strip will bend.

**EXAMPLE:**

Most bimetallic strips are made of copper and steel. Let’s say the copper part is on top. The steel part is on the bottom. Copper will expand more when heated. Therefore, the strip will bend downward. As it cools, the copper will shrink more quickly. This will cause the strip to bend upward.

- The bimetallic strip is generally attached to a pointer. As the metals bends, the pointer moves to show the temperature.

- Bimetallic strips are often wound into small coils. Those coils curl or uncurl with temperature changes.

- Bimetallic thermometers are used in ovens and older household thermostats.

**Quick Fact**

Ever have trouble opening a jar? If the jar is made of glass and has a metal lid, here’s a trick. Run hot water around the metal lid. The heat will cause the metal to expand. Once this happens, it will be easier to open the jar.

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**HISTORY: THERMOMETER**

In 1593, Galileo Galilei invented a water thermometer. As we know, water freezes at 0 °C. Therefore, the thermometers could not measure temperatures below the freezing point of water.

In 1714, Daniel Gabriel Fahrenheit invented the first mercury thermometer. Ten years later, he developed a temperature scale—the Fahrenheit scale.

More recently, alcohol replaced mercury in thermometers. Like mercury, alcohol also has a freezing point below the freezing point of water. Why use alcohol? Mercury is dangerous to humans. If a mercury thermometer breaks, it can be a hazard. Alcohol is considered to be a safer alternative.
MEASURING PRESSURE

Scientists use a variety of instruments to measure different forms of pressure.

**Manometer:** a device used to measure the pressure of a fluid.

- Manometers often measure pressure based on differences in the height and position of a column of liquid in a “U” tube.
- The legs of the manometer are connected to separate sources of pressure. The liquid will rise in the leg with the lower pressure and drop in the other leg.
- One leg of the tube is a reference leg, often left open to the atmosphere. The other leg of the tube is the measuring leg.
- Manometers are usually used to measure pressures close to atmospheric pressure.

![Manometer diagram]

**Po = reference pressure (open to atmosphere)**

**Pa = test pressure**

**Barometer:** a device (a type of manometer) used to measure atmospheric pressure.

- When the water or mercury level rises in a barometer, the air pressure is increasing. When the water or mercury level falls, the air pressure is decreasing.
- Mercury barometers are commonly used in weather reporting.

Most pressure gauges used today are aneroid (meaning “without fluid”). They contain a coiled tube, called a “Bourdon” tube.

- A Bourdon tube contracts like a spring when pressure increases.
- As the tube coils (or uncoils), it turns a pointer. The pointer is on the face of the gauge and marks the pressure.

**HISTORY: EVANGELISTA TORRICELLI (1608–1647)**

Evangelista Torricelli was an Italian physicist and mathematician. He developed the first mercury barometer in the early 1640s. (He was actually investigating vacuums.)

- He determined that the height of mercury was only $\frac{1}{14}$ the height of water. This is because mercury is fourteen times as dense as water.
- He noticed that the level of mercury varied from day to day. Therefore, he concluded that the difference was caused by changes in atmospheric pressure.
- He also determined that the space above the mercury in the barometer must contain a vacuum.

The “torr,” a unit of pressure, is named after him.
TRANSFERRING LIQUIDS

Pipette: a device used to measure and move a small amount of liquid from one container to another.

- Liquid is drawn up into a pipette by suction. A vacuum is created in the pipette. (How the vacuum is created depends on the type of pipette.) When the pipette is placed into a liquid, the vacuum creates a suction. The suction causes the liquid to move up into the pipette.

- Pasteur pipette: a long, skinny tube with a bulb at one end. These pipettes are like eye droppers.
  - When you squeeze the bulb, a vacuum is created in the pipette. When you release the bulb, the liquid moves up into the pipette.
  - These pipettes are used to move a liquid from one container to another. They do not provide accurate measurements.

- Volumetric pipette: a long, skinny tube with an enlargement in the middle and a suction device at one end.
  - These pipettes are used to accurately measure a specific volume of liquid.
  - The size of the enlarged middle section determines the volume for that pipette.
  - Therefore, these pipettes come in different sizes, usually ranging from 5 mL to 50 mL.

HEATING MATERIALS

In commercial laboratories, the most common ways of heating are with a hot plate, in a temperature-controlled oven, or over a Bunsen burner. The first two methods are generally preferred. This is because the heat is provided by an electric source. The lack of a flame reduces the risk of a fire. In classroom laboratories, hot plates and Bunsen burners are commonly used.

Bunsen burner: a gas burner that produces a single, steady flame for laboratory experiments.

- The flame burns at the top of a vertical metal tube connected to a natural gas source.
- A valve on the Bunsen burner controls the amount of gas that flows into it.
  - As more gas flows into the burner, the flame gets bigger.
- A “collar” controls the amount of air that mixes with the fuel. It can be rotated to control the amount of air flowing into the burner.
  - The amount of air affects the quality of the flame.
  - The ideal flame is bluish in color, not yellow or smoky.
HISTORY: **ROBERT BUNSEN** (1811-1899)

In 1855, Robert Bunsen improved the heating burner that is named after him. (He did not invent it.) Up until Bunsen's improvements, the burner's flames were smoky, flickered too much, and did not produce much heat.

A device called a spectroscope was initially invented in 1819 by Joseph Von Fraunhofer. However, Bunsen and his colleague Gustav Kirchhoff developed a spectroscope in 1859 that allowed them to discover the elements cesium and rubidium.

Bunsen learned his laboratory safety lesson the hard way. Early in his career, Bunsen was conducting research on arsenic compounds. One of the compounds exploded in his face, causing him to lose the use of his right eye.
OBJECTIVES

- Explain the importance of chemical safety and where to find chemical safety information.
- Identify common chemical safety and protective equipment symbols.
- List and describe basic laboratory safety guidelines and tips.

Chemicals are a part of our everyday lives. They have many beneficial uses. However, chemicals can also be hazardous if mishandled or misused. For this reason, it is very important that anyone using chemicals understands how to safely store, handle, and use them.

WHERE TO FIND CHEMICAL SAFETY INFORMATION

A good place to find chemical safety information is on the label of the chemical’s container. Product container labels include important information about storage and handling. They may also include warnings, first aid information, and other emergency details.

Many commercial chemical containers will have an image with a symbol similar to the one shown below. This symbol gives a very quick overview of things to consider when storing or handling the chemicals. The diamond is divided into four sections. Each section displays a hazard rating from 0 to 4. A zero indicates no hazard. Higher numbers stand for increasing precautions that need to be taken to safely work with those chemicals.

- **Health** rating: indicates the degree of harm that exposure to the substance would cause a person. It indicates the amount of protective equipment a person needs in order to safely work with this substance. A rating of 4 would most likely mean that specialized equipment is needed to work safely, while a rating of 1 may mean that only basic protection, such as goggles and gloves, is needed.

- **Flammability** rating: indicates the likelihood of the substance to vaporize, ignite, and burn.

- **Reactivity** rating: indicates the likelihood of the substance to release energy by chemical reaction or explosion.

- **Special Warning** section: provides any extra safety information or warnings.
  - The symbol shown above (a “W” with a line through it) means that the chemical reacts with water. This extra information tells us to keep the chemical away from water.
  - Other common symbols for the special warning section are: OXY (oxidizer), ACID (acid), ALK (alkali), COR (corrosive), and RAD (radiation hazard).
Labels should also contain more information about the chemical, such as the name, where it was manufactured, precautionary statements, and other information that will help you safely handle that chemical. The image below shows what a label might look like².

Another information source is the **safety data sheet (SDS)** for a chemical. SDSs are available for most chemicals and are prepared by the manufacturer of a product.

An SDS gives workers, emergency personnel, and all of us information about the proper way to handle or work with a certain substance.

An SDS includes:

- Detailed information about the chemical identity and all ingredients of the product.
- Physical and chemical properties of the product (melting point, boiling point, etc.).
- Potential hazards associated with the substance (health, storage cautions, flammability, radioactivity, reactivity, etc.).
- Emergency actions and first aid procedures if an accident happens.
- Storage and handling precautions.
- Safe disposal information.

In addition, an SDS includes information to identify the manufacturer. This includes the manufacturer’s address, as well as emergency phone numbers. Not all SDSs may look the same but they all must contain the required information.


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**Quick Fact**

The Occupational Safety and Health Administration (OSHA) recently made changes to the way that chemical safety information is communicated. These changes are meant to allow people to better understand how to safely handle chemicals. Beginning in June 1, 2015, all chemical labels should have basic information about how to safely handle and work with those chemicals. People that work with chemicals will start to see labels that might look like the one to the left.
Anyone working with chemicals should become familiar with these common warning symbols. These symbols are often found on chemical containers and around laboratories. They may seem intimidating, but their job is to keep people informed of any potential hazards. They are designed to be noticed! Ultimately, they help make sure that people use chemicals responsibly to keep us safe. If you see these symbols, pay attention, follow instructions carefully, and look for other information about the chemical.

**EXAMPLE:**

The safety data sheet (SDS) for water will tell you that it's a clear liquid, it's not a health hazard, it has a boiling point of 100 °C, and will give you many other properties of water. Although you may have already known this information about water, you can look up SDSs for other chemicals and find similar information.

### WARNING SYMBOLS

**Gas Symbol**

The gas symbol indicates that there are gases that may be compressed, under pressure, or in other forms that may require special care when handling.

**Environmental Hazard Symbol**

The environmental hazard symbol indicates that the chemicals contained are hazardous to the environment and to aquatic life. This symbol is especially important during disposal. You will want to be careful about how to dispose these chemicals to avoid causing any harm.

**Explosive Symbol**

The explosive symbol indicates the potential for an explosive situation. The substance may explode if it comes into contact with fire or if it experiences shocks or friction. Read and follow instructions to handle these chemicals safely.

**Flame Symbol**

The flame symbol indicates the presence of a flammable substance.

- A flammable substance is one that easily ignites.
- Flammable substances include gasoline, propane, and ethanol.

When working near an open flame, tie back or cover loose hair and avoid loose or bulky clothing. When working with a flammable substance, be sure to avoid anything that could start a fire, such as electrical sparks or a hot surface.

**Corrosive Symbol**

The corrosive symbol indicates the presence of a substance that can cause damage to skin, eyes, and can potentially destroy metals. These substances can destroy or cause major damage to other substances. Often times thes corrosives are strong acids or bases. As with other chemicals, remember to avoid contact with skin, eyes, and clothing and do not inhale the vapors.

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**Important:**

These warning symbols are used as part of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS). These symbols are used to label chemicals in many countries, making it easier for people to understand potential hazards and learn how to safely handle chemicals.
The oxidizer symbol warns you to keep the substance away from flammable and combustible materials. An oxidizing substance easily gives off oxygen, transfers oxygen atoms, or behaves like oxygen in a chemical reaction. Just because a substance is an oxidizer does not mean it is combustible. However, oxidizers can fuel a fire and make it more difficult to put a fire out. (The definition of an oxidizer for safety classifications is different than the definition used by analytical chemists.)

This warning, or irritant and sensitizer, symbol is used to indicate those toxic chemicals. Although these chemicals are still hazardous, they indicate a less severe toxicity than those labeled with the skull and cross-bones or the chronic health hazard symbols. These chemicals can cause irritation and be harmful if you come in contact with them, so you should always work safely and pay attention to other hazard information about them.

The skull and cross-bones, or acute toxicity, symbol is used to indicate a health hazard. It often means that there is a toxic or poisonous substance inside the container with the symbol or in close proximity to that location.

The chronic health hazard symbol is used to indicate chemicals that are very harmful to the human body. Chemicals with this symbol can be toxic or somehow detrimental to your health. You should always look for other instructions to safely handle these substances. As with the other health symbols mentioned above, do not let such a substance come in contact with your skin. Do not eat or drink the substance, and do not inhale its vapors. If you do come into contact with a substance labelled with this symbol, you should seek medical attention or call a poison control hotline.

Here are a few other warning symbols and their meanings:

- The radiation symbol (the “trefoil”) means that a substance is radioactive. Instructions should be followed carefully to avoid harmful exposure.

- In 2007, a new radiation symbol was released. The different images in this symbol are designed to provide a more obvious and powerful warning than the previous radiation symbol.

- The biohazard symbol warns of a biological substance that is dangerous to humans or the environment. These include syringes and other medical devices that have come into contact with bodily fluids. These devices could carry harmful diseases. Therefore, they should be labeled with the biohazard symbol.

- Lasers can damage skin and eyesight. Even low-powered lasers can cause severe damage to eyesight.
  - Lasers produce an intense and narrow beam of single color light.
  - Laser beams can travel long distances and can carry huge amounts of energy.

*Please note that more information on warning symbols and updates to the Safety Data Sheets can be found online at OSHA’s website: https://www.osha.gov/dsg/hazcom. Be sure to ask your teacher or educator if you would like more information.*
PROTECTIVE EQUIPMENT SYMBOLS

Other symbols tell you what equipment you should wear to keep you safe.

The **respiratory protection** symbol means that you should wear a protective mask or other facepiece. The symbol is used in areas where a person may be exposed to contaminated air.

The **hand protection** symbol indicates when gloves must be worn. Be sure to find out what type of glove is needed. Thermal gloves are used for handling hot and cold materials. Leather gloves are used for handling rough or scratchy materials. Nitrile gloves are used to protect against chemical solvents and potentially infectious substances.

The **protective footwear** symbol indicates that you should wear protective boots or shoes. Sharp or falling objects, hazardous liquids, or heavy materials can injure your feet. These injuries can be prevented by wearing protective footwear.

The **eye protection** symbol means that safety goggles or other eye protection is required. Be sure to figure out what type of eye protection should be worn before entering an area marked by this symbol. Industrial safety glasses protect the eyes from sharp, flying objects. They generally do not seal completely around the eyes. However, they do provide more coverage than regular glasses. In addition, industrial safety glasses can be made to match a person’s vision prescription. Safety goggles are made to fit completely around the eyes. They protect against sharp flying objects, splashing liquids, and dust.

The **face protection** symbol indicates that full face protection is required. A face shield is a good example of full face protection. Face shields protect your entire face from splashing liquids or other potentially hazardous materials. For the best protection, you can also wear safety glasses or goggles under the face shield.

Quick Fact

Exposure to low temperatures may damage the skin just as much as a heat burn. For example, liquid nitrogen and dry ice are very cold substances that should be handled carefully. Appropriate thermal hand protection must be worn when working with either hot or cold substances.

Quick Fact

Most of the symbols described are meant to prevent injury. Other symbols are used to guide you in an emergency. For example, the symmetrical cross symbol shows you where the first aid kit or station is located. There are also symbols to direct you to the safety shower, eyewash station, and emergency exits. See if you can find what these symbols look like.
GENERAL SAFETY RULES

Scientists take special care when working in the lab and performing experiments. They are careful to choose the safest chemical to work with, follow safe practices, and understand all potential hazards. You should do the same.

Three basic principles guide the general safety rules for storing, handling, and using chemicals. Those principles are keeping people safe around chemicals, keeping reactive chemicals away from each other, and practicing good chemical hygiene. Some general rules to remember are provided in this section. However, remember to always follow the specific safety instructions for the place you are working and for the materials you are using.

- **Always read through directions completely before beginning an experiment.** Read the SDSs of the chemicals you are using to find out what precautions you should take in order to safely perform your experiment. This will let you plan your experiment appropriately.

- **Never work alone.** Make sure an adult helps you with your experiment. Scientists today almost always work with partners or assistants. It’s good practice to have someone else around in case of an emergency.

- **Wear appropriate clothing when working.** Remove jewelry, such as dangling necklaces, chains, and bracelets. Secure long sleeves, remove loose garments, and wear shoes that cover your entire foot (from toes to heel). Wear glasses instead of contact lenses. If you are wearing contact lenses, be sure to tell your teacher. Tie back or cover long hair, especially near an open flame.

- **Wear safety goggles to protect your eyes.** You only have two eyes, and they are just a couple of inches away from each other. If a substance splashes up, it could hurt both of your eyes. Safety goggles, unlike regular glasses, cover your eyes completely. Many injuries can occur to the sides of your eyes. Regular glasses do not provide protection on the sides. Safety goggles do. Safety goggles and other splash protection are especially important whenever mixing or pouring chemicals.

- **Wear a lab coat or apron to keep chemicals off your regular clothes.** Lab coats should be buttoned all the way. Sleeves should be rolled down to completely cover your arms. Lab coats should be removed when you leave the lab to avoid contaminating public places or your home.

- **Wear the proper type of gloves for the experiment you are doing.** Different types of gloves are available for working with certain substances. These different gloves are made of different materials. For example, thermal gloves, rubber gloves, and nitrile gloves are all made for different tasks. You should also be sure to remove your gloves before touching any surfaces that other people may touch when they are not wearing gloves (such as door handles).

- **Know where safety equipment is located.** Make sure you know how to use the equipment. Safety equipment includes the fire extinguisher, safety shower, eye-wash station, fire blanket, first aid kit, and fire alarm. Notify your teacher immediately about any injury or chemical spill.
• Avoid touching your eyes or mouth when working in the laboratory. When you have an itch on your face or think something got into your eye, it’s easy to forget this rule. If you need to touch your face for any reason, make sure you remove your gloves and wash your hands well first.

• Keep your face away from the opening of a container that holds chemicals. Do not smell any chemical directly. Chemists use a process called wafting to smell chemicals. An open chemical container is held several inches away from your nose. You then use your free hand to “fan” the vapors escaping from the bottle toward your nose. When testing for odors, use a wafting technique to direct the odors to your nose.

• Do not eat or drink in the laboratory. Chemicals in the lab, and even particles in the air, may accidentally mix with your food or drink. If this happens, you will end up eating those chemicals by accident. Likewise, food and drinks may contaminate the chemicals in the lab.

• Be careful when working with sharp objects like scissors or knives. Always cut in the direction away from your body. When storing sharp objects, be sure the blades are not exposed.

• When mixing chemicals, follow the instructions carefully. You should be sure to mix them in the right order. If your instructions say to put chemical #1 in a beaker and then add chemical #2, be sure you follow that order. Do not put chemical #2 in the beaker first.

• Do not play jokes or mess around when conducting experiments. Chemistry is fun, but it is not safe to play jokes or mess around in the lab. You should focus on the experiment you are performing. If you’re not paying attention, you or someone else can get hurt.

• Do not play Mad Scientist! Never mix chemicals just to “see what happens.” The chemical reactions and explosions you may see on TV science programs might look cool, but they are created by experts who know how to run the reaction safely and take proper precautions. Do not try to create these reactions or explosions at home or in your class!

WHEN STORING CHEMICAL SUBSTANCES:
• Label all storage areas and containers clearly. Be sure these labels are visible and updated as needed.

• Avoid storing chemicals in areas that are difficult to see or reach. Avoid storing chemicals on top of cabinets or on shelves above eye level. You want to make sure people can easily see chemical labels and reach the containers safely.

• Reactive chemicals should never be stored near each other. For example, acids and bases should be in separate areas to prevent them from accidentally mixing. Therefore, you should not store chemicals alphabetically. Otherwise, reactive chemicals may end up next to each other in the storage area.

Think About It...
Do you follow the same safe chemical storage practices at home that you follow in the laboratory? What do you have stored under your kitchen sink or in utility room cabinets? Which items are acids? Which are bases?
WHEN POURING LIQUIDS FROM ONE CONTAINER TO ANOTHER:

- Keep the label of a chemical bottle against the palm of your hand. Then, if any of the substance drips from the bottle, it will only touch the opposite side of the bottle. Everyone in the lab should follow this same practice. That way, the next person to use the bottle will not risk getting any of the chemical on his/her skin. (Though, remember, you should be wearing gloves!)

- Use a glass stirring rod to pour a liquid into a beaker. Pouring the liquid down the glass rod into the beaker helps to prevent splashing.

- If you are transferring a liquid to a small-mouthed vessel (like a test tube), pour the liquid into a beaker or graduated cylinder first. Beakers and graduated cylinders usually have a pouring lip. This lip gives you better control when transferring the liquid.

- When an acid must be mixed with water, always add the acid slowly to water. To remember this, think A & W (like the root beer!). The acid goes into water. Mixing the other way around, by adding water to an acid, could result in a violent reaction.

WHEN HANDLING GLASSWARE:

- Do not use glassware that is chipped or cracked. If you have a broken piece of glassware, dispose of it properly. If a piece of glassware breaks into pieces, notify your teacher. Do not touch the broken glass, and do not try to clean up the broken glass yourself.

- Do not place hot glassware directly on a table. Always place some kind of insulating pad between the glass and the table surface.

- Allow plenty of time for hot glass to cool before touching it. Remember, hot glass may look like it has cooled, but it can still be very hot!

WHEN HEATING SUBSTANCES:

- Never leave a flame or other heating instrument unattended.

- Do not use electrical cords that have frayed ends, bare wires, or loose plugs. These problems can cause fire hazards or injury. Electrical cords, outlets, and equipment should also be kept away from water. When heating a liquid substance on an electrical device (like a hot plate), be sure the liquid is contained properly.

- Do not let electrical cords lay across work spaces. Try to keep the electrical device close to the outlet so the cord is not stretched over a large distance.

- Never reach across an open flame or other heating device. Even if you do not touch the device, the heat rising from it can cause injury.

- Never look into a container that is being heated. When heating a test tube, point the opening (mouth) away from yourself and other people. As it is heated, the substances inside may quickly shoot out of the tube.
• Never heat a closed container. Generally, an increase in temperature causes an increase in pressure. Inside a closed container, pressure may build up to the point that the container breaks or bursts apart.

• Do not bring any substance into contact with a flame. Unless you are specifically instructed to do so, you should never touch a substance directly to a flame. Heating a substance near a flame and actually touching the flame can have very different results.

• Avoid extremes when heating substances. Do not put cold glassware on hot surfaces.

• Use tongs when removing glassware or other containers from a heat source to avoid burns.

WHEN CLEANING UP, BE SURE TO:

• Turn off all heating instruments and disconnect any electrical equipment.

• Return all materials to their proper places. All equipment should be cleaned according to instructions and stored in the proper places. Do not return chemicals to the original containers. Your teacher will tell you what to do with the unused chemicals and how to dispose of any other materials.

• Do not simply dispose of chemicals down the drain! Some chemicals can be washed down the drain. Others require a different method of disposal. Make sure you ask your teacher what substances can go down the drain. If a chemical can go in the sink, be sure to wash it away completely. Otherwise, if you have not completely washed away one substance, another substance you pour in the sink later may react with the leftovers.

• Clean and dry your work area. Do not leave water on the counter or floor.

• Wash your hands with soap and water after completing an experiment. Remember, be sure not to touch your eyes or mouth until you have washed your hands.

• Keep your work space uncluttered. Remember, cleaning up after an experiment is easier when you start with a clean and organized workspace.
NOW YOU’RE READY FOR THE

CHALLENGE

GOOD LUCK!