YOU BE THE CHEMIST CHALLENGE™

PASSPORT TO SCIENCE EXPLORATION:
THE CORE OF CHEMISTRY

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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 understand and gain knowledge about the world around them. You have probably thought like a scientist to solve problems and answer questions. You probably began with a thought like "I wonder why this happens." People are curious by nature, and science helps people find answers to questions or further understand their surroundings.

Quick Fact

Scientist Carl Sagan once said, "Science is a way of thinking much more than it is a body of facts."

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 way 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 and scientific inquiry in different ways. Scientific inquiry and the scientific method use the following basic concepts:

- Observation
- Research
- Hypothesis
- Experiment
- Data collection & analysis
- Conclusion
- Communication of ideas and results

Quick Fact

Keep in mind, the scientific method is a simplified introduction to the real-world scientific process. All of these steps ARE used by scientists, but in many combinations along with other important scientific practices. Understanding these steps is just the beginning of understanding scientific inquiry.

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 guide scientists in their research and can usually be answered by collecting evidence.

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 that 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 to freeze than the other?**

Quick Fact

Not all questions are scientific questions. If you ask someone what the best meal is on a menu, the answer you get will be an opinion. It is not based on evidence. A scientific question is answered using evidence.

BACKGROUND RESEARCH

After asking a question based on their observations, scientists do **research** on the topic they're investigating. Many scientists and students spend time reading papers and books on past research before beginning their own experiments. Often 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, and may even lead scientists to change their original question.

When doing research, scientists have to make sure the information they use is from *credible* (trustworthy) sources.

Think About It...

Websites can be updated with new information almost immediately. Updating the information in a book takes longer. What other aspects about these sources should you consider before deciding?

EXAMPLE:

Your friend writes a paper on why they think dinosaurs went extinct without doing any research. On the other hand, a team of 10 scientists studied the earth and the bones of dinosaurs for years and wrote a paper on their findings, which was reviewed critically by another team of scientists. The paper written by the team of scientists is considered to be more credible.

When conducting research, it is also important to look for gaps or errors in prior findings and research. There are often several explanations for why something happens. If only one factor is tested in an experiment or only one factor is included in an explanation, the results will only reflect part of the answer.

EXAMPLE:

A group of scientists conducts an experiment to determine whether 5th grade students learn better when they work in groups or when they work individually, and find that the students learn better when working individually. When you review their research, you notice that they conducted their experiment at an all-boys school. Would the answer be different if girls were included in the experiment?

Even so, the experiment gives useful information. It may also 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 state clearly what they plan to test during their experiment. This statement is called a **hypothesis**, which is a predicted answer to a scientific question or an educated guess that may explain an 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 than the cold water.**

A scientific hypothesis must be *testable*. For example, the hypothesis above can be tested by conducting an experiment that measures the time it takes for ice cubes to form from water starting 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 factor that was changed. If the experiment is not designed carefully, the results may be confusing and will not help to assess the hypothesis. Designing an experiment can be tricky and it may take several tries to get it right.

EXAMPLE:

To test your hypothesis about the effect of temperature on the rate at which ice cubes form, there are a few factors you must first consider:

- **How soon after you measure the temperature should the water go into the freezer?**
- **Should the amount of water you use each time be consistent?**
- **Should you get water from the same source (such as a kitchen sink or a bottle of water) each time?**

Quick Fact

The example provides possible problems to consider for the experiment. These problems can help identify variables that should be controlled.

DATA COLLECTION & ANALYSIS

Data are pieces of information collected before, during, and after an experiment. It is important to keep detailed notes and to record all data during an experiment so that it can be analyzed after completing the experiment to determine the results. Sometimes data make 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:

To conduct your experiment, you set up 2 cups of water at different temperatures. You measure the temperature of the first cup of water and record a measurement of 25 °C in your notebook. Likewise, you determine that the temperature of the second cup is 55 °C and record this measurement in your notebook. You also make a note that you should consider comparing the results to cups of water at other temperatures, such as 35 °C and 45 °C. As you conduct your experiment, you write down the amount of time it takes for each cup of water to freeze and any other observations that you make. Then, you can show the results in a graph that illustrates the freezing time in relation to the starting temperature. You can also repeat the experiment to make sure that your results can be reproduced, which would indicate that you can trust your data.

Quick Fact

Although people have begun to use data as a singular noun meaning "information," data is actually a collective term. It is the plural form of "datum."

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 the hypothesis was correct.

- 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 will often report their findings in journals or speeches to tell others what they have learned. 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 when other people 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 vary only one factor of their experiment at a time so that they know that the results are related to the one factor that was altered. 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 while changing the temperature of the water. 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 can be changed and controlled in an experiment are known as **variables**:

- **Independent variable:** the variable scientists change in the experiment. This is also known as the *manipulated variable*.
- **Dependent variable**: the variable scientists observe or measure to see if it is affected by a change in the independent variable. This is also known as the *responding variable*.

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

EXAMPLE:

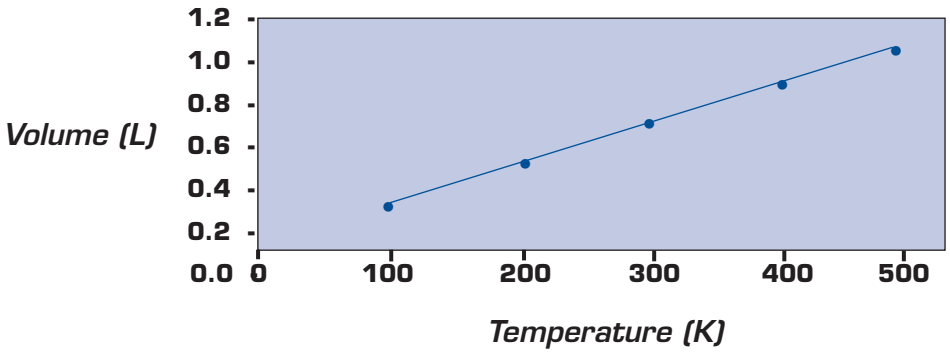
A student wants to know if water at different temperatures will freeze at different rates. The independent variable is the water temperature, because hot and cold water will be tested. The dependent variable is time, because the amount of time it takes for ice to form depends on whether it is hot water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



Graphing data can help to explain the results of an 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 eliminate confusion about the outcome because only one factor is 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 understand what happens when you don't make any changes (when the setup is left alone). In the other setups, or **experimental groups**, the independent variable is changed. Control groups and experimental groups are set up exactly the same except for one variable. After an experiment, scientists 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 is 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 to make sure that the comparisons being made 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. If one box is larger or smaller than another, that may affect the student's results.

SCIENTIFIC 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 another 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.

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

- Scientific theories are not facts, but they have been accepted as true by the global scientific community. They may change if new information becomes available.
- To become a scientific theory, an idea must be tested over and over, producing the same results.
- Theories are scientifically accepted explanations of why something occurs. They can be used to predict the results of future observations.
- Examples of scientific theories include the Theory of Relativity, the Kinetic Molecular Theory, and the Theory of Evolution.

SCIENTIFIC 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 another law.
- Laws generally state that a particular event or thing will always occur if certain conditions are met.
- Many scientific laws can predict events and phenomena so well that they are expressed as mathematical equations.
- Examples of laws include the Law of Conservation of Energy, Newton's Laws of Motion, and the Ideal Gas Law.

SECTION II: MEASUREMENT

OBJECTIVES

- Demonstrate the difference 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. In this case, a ruler is required to figure out an object's length.

CERTAINTY IN MEASUREMENT

Scientists can use **accuracy** and **precision** to describe the quality of 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.

Quick Fact

Precision is easier to determine. You can see how close one measurement is to another.

Accuracy is more difficult because scientists might want to measure things that are not already known.

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.

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!

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. The mass of an object affects how difficult it is to change the object's speed or direction of motion.

- 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.
- Scientists measure mass in kilograms (kg) or grams (g).

Quick Fact

Another way to measure mass is to see how hard it is to change the object's velocity (speed and direction of motion). 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 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 increases too.

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.
- Scientists measure weight in Newtons (N). This is the same unit that is used to measure force.
- In the U.S. customary units system, people often measure weight in pounds (lbs).

- Weight is not the same as mass but the two measurements are related. Two pennies have twice as much mass as one penny 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. Weight is related to mass by the equation $W = m \times g$, where m is mass and g is acceleration due to gravity.

Quick Fact

Mass vs. Weight:

Most of us know how much our body weighs. Now, we have learned that this measurement is different from our body's mass. The gravity on 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 as it is on the moon.

WEIGHT ON OTHER PLANETS

The table below shows approximately what a person who weighs 100 pounds on Earth (and has a mass of 45.4 kg) would weigh on other planets:

Planet	*Mercury*	*Venus*	*Earth*	*Mars*	*Jupiter*	*Saturn*	*Uranus*	*Neptune*
Weight (in pounds)	38	88	100	38	235	105	89	120

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 or takes up.

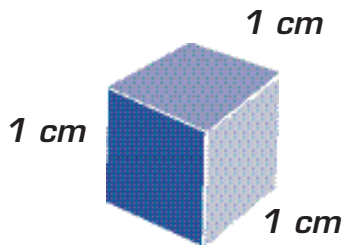
- Scientists measure volume in units of liters (L) or cubic centimeters (cm^3 or cc). One cubic centimeter is equal to one milliliter (mL).
- Volume can be measured in different ways (see the Laboratory Equipment section).
  - To find the volume of a liquid, you can simply pour the liquid into a graduated cylinder.
  - To determine the volume of a rectangular solid, follow the steps below:
    1. Measure the length, width, and height of the solid. Write down your results for each of these measurements.
    2. Multiply your three measurements together. This product is the volume of the solid.

Volume (V) = length (l) × width (w) × height (h)

$V = l \times w \times h$

EXAMPLE:

The length, width, and height of the box below are each 1 cm. If you multiply these numbers (1 cm × 1 cm × 1 cm), you get a volume measurement of 1 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?

$$V = l \times w \times h$$
$$V = 2\ cm \times 1\ cm \times 4\ cm$$
$$V = 8\ cm^3$$

Quick Fact

One thousand cubic centimeters (cm^3) equals one liter (L). 1,000 cm^3 = 1 L

Quick Fact

When you multiply measurements together, their units are also multiplied. Volume has the units of cm^3 because the length, width, and height use centimeters: cm × cm × cm = cm^3

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

- A device that measures temperature is called a thermometer.
- Scientists generally measure temperature in degrees Celsius (°C) or Kelvin (K).
- The Kelvin temperature scale is actually a shifted Celsius scale that includes absolute zero (0 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 °C. That temperature in Kelvin is about 298 K. The answer is derived using the following calculation: 25 °C + 273.15 = 298.15 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.

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.

Think About It...

In degrees Celsius, the freezing point of water is 0 °C, while the boiling point is 100 °C. What are the freezing and boiling points of water in Kelvin?

FORMULAS:

$[K] = [°C] + 273.15$ — **K = Kelvin: the metric scale for absolute temperature**

$[°F] = (1.8 \times [°C]) + 32$ — **°F = degrees Fahrenheit: scale generally used in the United States**

$[°C] = \frac{[°F] - 32}{1.8}$ — **°C = degrees Celsius: the metric scale for temperature**

DENSITY: the amount of matter per unit of volume. Density measures how much matter occupies a given amount of space. An object that is very dense is very compact, so it has a large number of particles in a confined amount of space.

- Density gives the relationship between two measurements: mass and volume. A higher density means that there is more mass per unit of space.

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

- To calculate density, you must find the mass and volume of the substance. Scientists usually use kilograms per cubic meter (kg/m^3), grams per milliliter (g/mL), or grams per cubic centimeter (g/cm^3 or g/cc) to measure density depending on the substance.

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?

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/cc at 4 °C. Therefore, 1 cubic centimeter of water has a mass of 1 gram. At 20 °C, the density of water is 0.998 g/cc.

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

Quick Fact

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

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.

- 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.
2. Pour some of your liquid into the graduated cylinder. Write down the volume of the liquid.
3. Place the graduated cylinder with the liquid inside on the balance. Write down your new measurement. You don't want to spill any liquid on your balance.
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.

- 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.

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.

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

$$p = \frac{\text{Force}}{\text{Area}} = \frac{F}{A}$$

- 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.
- Air 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

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 × width

Quick Fact

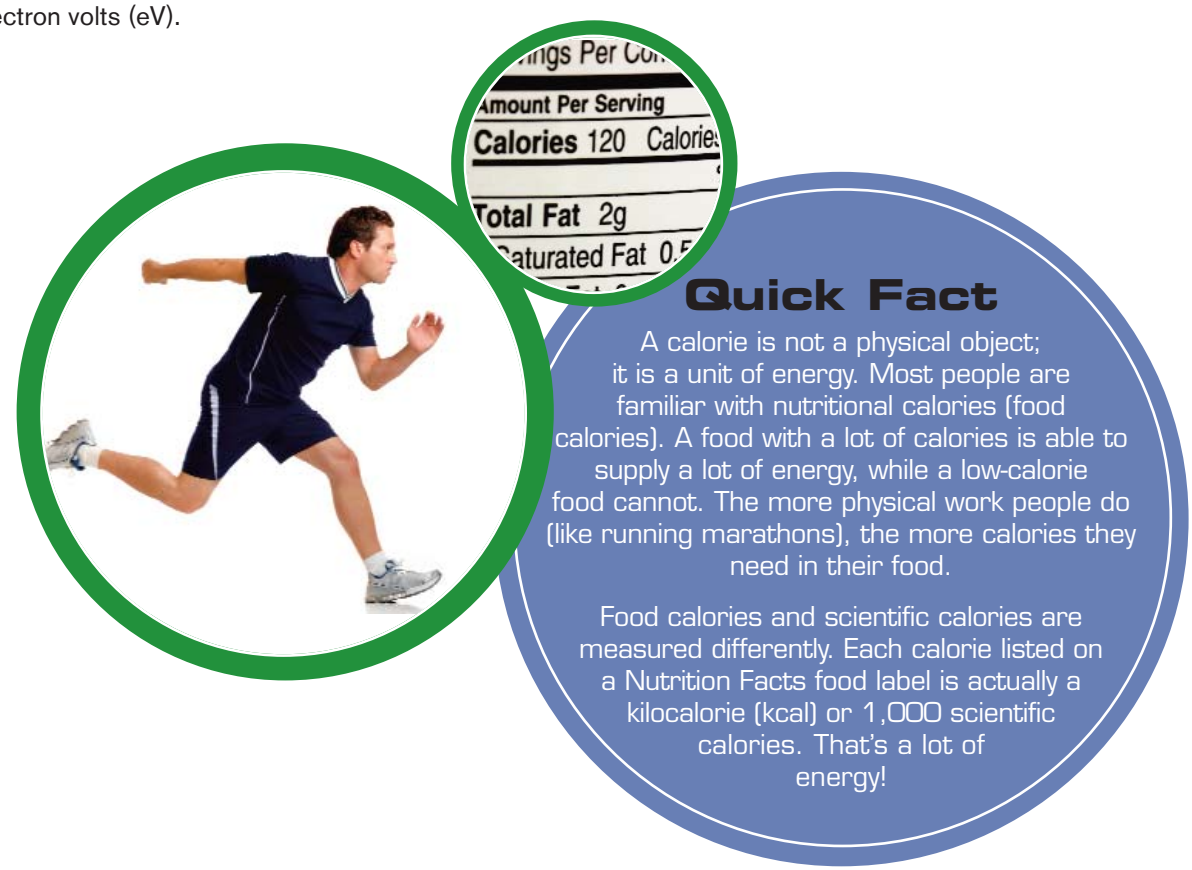
Air pressure on the earth changes with altitude. At sea level, the air pressure is about 1 atm or 14.7 pounds per square inch. This means that every square inch of our bodies has almost fifteen pounds (the weight of a heavy bowling ball) pushing on it. At higher altitudes, air pressure drops, so people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

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 people do (like running marathons), 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!

NOTES

MEASUREMENT

The table below summarizes the measurements and corresponding units described on the previous pages.

Measure	What It Measures	Scientific Units	U.S Customary Units (Old English Units)
Mass	The amount of matter in an object	Kilograms (kg), grams (g)	Pounds, stones
Length	How long an object is or the distance an object spans	Meters (m)	Inches, feet, miles
Volume	The amount of space an object occupies	Liters (L), cubic meters (m^3), cubic centimeters (cm^3 or cc)	Pints, quarts, gallons
Temperature	The average kinetic energy of particles	Degrees Celsius (°C), Kelvin (K)	Degrees Fahrenheit (°F)
Density	Ratio of mass to volume for an object	Kilograms per cubic meter (kg/m^3), grams per cubic centimeter (g/cc), grams per milliliter (g/mL)	Pounds per cubic inch
Pressure	The amount of force per unit area	Pascals (Pa), atmospheres (atm), torrs (torr), millimeters of mercury (mmHg)	Pounds per square inch (psi)
Energy	The ability to do work or generate heat	Joules (J), calories (cal), electron volts (eV)	British Thermal Units (BTU)

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 have the same density.

Quick Fact

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. For example, they tell you what smell something has or what color it is.

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.

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 United States 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 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:

Measure	Base Unit
Length	Meter (m)
Mass	Kilogram (kg)
Time	Second (s)
Temperature	Kelvin (K)
Amount of a substance	Mole (mol)
Electric current	Ampere (A)
Luminous intensity	Candela (cd)

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 quantities they represent:

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.

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

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 developed based on the seven base units. The table below lists some common derived units:

Measurement	Derived Unit	Base Units	Derived Unit Symbol
Volume	Liter	$10^{-3} \times m^3$	L
Force	Newton	$kg \times m/s^2$	N
Energy, work	Joule	$N \times m$	J
Pressure	Pascal	N/m^2	Pa
Power	Watt	J/s	W
Electric potential	Volt	W/A	V
Resistance	Ohm	V/A	Ω
Frequency	Hertz	1/s	Hz

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 x 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 kg × 3 m/s^2. You get an answer of 0.6 Newtons, so 0.6 Newtons are needed to move the car.

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 quickly convert measurements between large and small values. 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 covert the amounts into the same units.

$$0.01\ \cancel{g} \times \frac{1{,}000\ \text{mg}}{1\ \cancel{g}} = 10\ \text{mg}$$

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.

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 cm = 10.0 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 units.

1.0 µg = 0.001 mg
1 microgram = 0.001 milligrams (or one thousandth of a milligram)

SCIENTIFIC NOTATION

Scientific notation is the method scientists use to quickly write 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 m/s = **3 × 100,000,000 m/s**

2. Write the last number above (the 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 m/s = 3 × 100,000,000 m/s = ***3×10^8 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 ft = 5.28 × 1,000 ft = ***5.28×10^3 ft***

When using scientific notation, 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. First, move the decimal in the appropriate direction. Move the decimal to the right for small numbers and to the left for large numbers. Then, count the number of places the decimal 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 5.28×10^3 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 2.2×10^{14} 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.

$$0.000025 \text{ m} = \frac{2.5}{100{,}000} \text{ m}$$

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, $1/100 = 1/10^2 = 10^{-2}$.

4. Rewrite the number using steps 1, 2, and 3.

$$0.000025 \text{ m} = \frac{2.5}{100{,}000} \text{ m} = \frac{2.5}{10^5} \text{ m} = \boldsymbol{2.5 \times 10^{-5} \text{ m}}$$

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

Quick Fact

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

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

QUICK STEPS FOR SMALL NUMBERS

To change a small number into scientific notation quickly, use 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 2.5×10^{-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 25×10^{-6} meters or 25 micrometers.

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. **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:** a uniform substance made up of one type of particle, which can be either an element or a compound.

   - Pure substances have the same composition and chemical structure 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 but not chemically. Most of the things around you are mixtures.

   - A mixture can be classified as either homogeneous or heterogeneous (see pages 29–30).

Quick Fact

The words homogeneous and heterogeneous might be easier to understand by exploring the meanings of the words themselves. The Greek prefix "homo" means "same," and the prefix "hetero" means "different." The suffix "genos" means "kind."

- 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.

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.

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 (H_2O) and salt (NaCl). Therefore, you can heat the salt water to make the H_2O 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 O_2 (diatomic oxygen) and O_3 (ozone). Two solid allotropes of tin are gray tin and white tin.

O

OXYGEN

Atomic #8

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. *Diatomic 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.*)

Think About It...

Look at the element box for oxygen. Can you identify some physical properties? What color is diatomic oxygen? What about chemical properties? Is oxygen reactive?

Sn

TIN

Atomic #50

According to archaeological findings, tin is one of the first 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 (SnO_2)
- 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 of any element (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.

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 H_2O. Other familiar compounds include table salt (NaCl), glucose ($C_6H_{12}O_6$), and sulfuric acid (H_2SO_4).
- There are millions of different known compounds. Scientists develop and study new compounds every day.
- A **binary compound** is made up of two different elements, such as sodium chloride (NaCl) and carbon dioxide (CO_2). A **ternary compound** is made up of three different elements, such as glucose ($C_6H_{12}O_6$) or silver carbonate (Ag_2CO_3).

Quick Fact

Stannous fluoride (SnF_2) 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.

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.

$$P_{total} = P_1 + P_2 + P_3 + \ldots$$

MIXTURES

Homogeneous mixture: a type of mixture that appears uniform throughout. The components are mixed evenly, so that the composition is consistent throughout. Differences in components of the mixtures are seen at the scale of atoms and molecules (see Atomic Structure section).

EXAMPLE:

Apple juice is a homogeneous mixture. The juice at the top of your glass is the same as in the middle, at the bottom, and in every other 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 (solutes) are dissolved in another substance (solvent). Solutions are made up of elements or compounds mixed together at the 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 smaller quantity.
  - **Solvent**: the substance that the solute is dissolved in. The solvent is usually the substance that is present in a greater quantity.

EXAMPLE:

Dissolving salt in 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).

Quick Fact

If both the solute and solvent exist in equal quantities, the substance that is more often used as a solvent is designated as the solvent. For example, in a 50% ethanol and 50% water solution, water is considered the solvent.

Water is often referred to as a "universal solvent" because it dissolves more substances than any other liquid.

- Some substances will dissolve more easily than other substances.
  - A substance that dissolves in another substance is **soluble** in that substance. 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 solvent does not mean it is soluble in all substances. While salt is soluble in water, it is insoluble in oil.

Heterogeneous mixture: a type of mixture in which the components are not mixed evenly or uniformly distributed throughout. Different samples from the mixture may have different properties and look distinct.

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 minute particles are spread evenly throughout another substance. The particles in a colloid tend to measure about one micrometer to one nanometer. Because of the tiny size of those particles, some colloids look like solutions, but 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 can't see the difference in size between colloid particles and particles in a solution 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.
- Colloids are classified according to the state of the dispersed particles and the substance in which they are dispersed.

- **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 CO_2 gas in the liquid.

Quick Fact

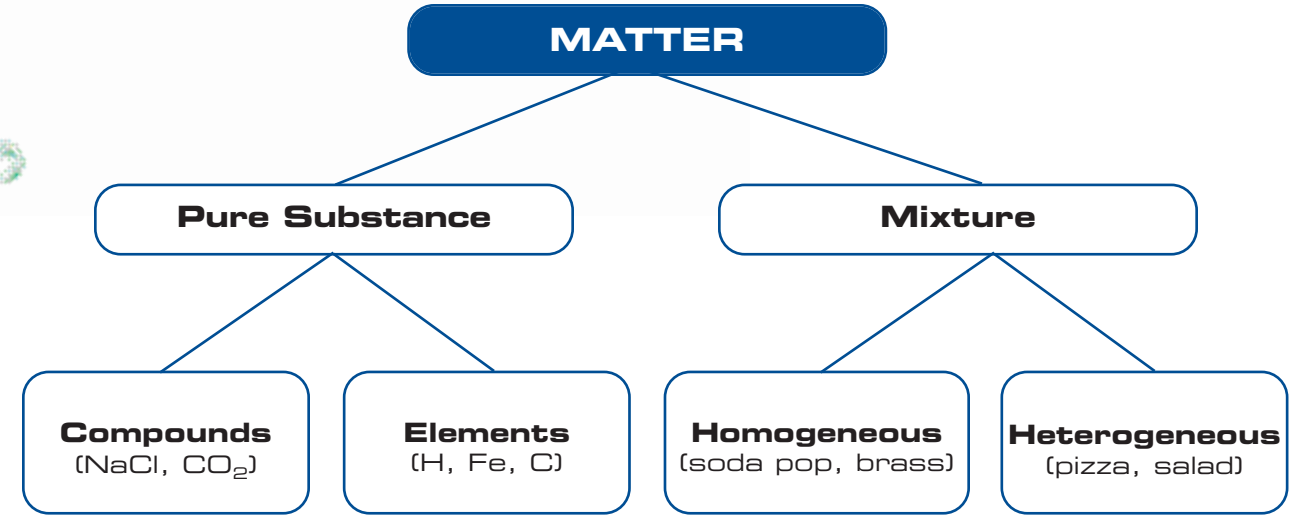
Sometimes, it is hard to figure out if a mixture is heterogeneous, homogeneous, or a colloid. For example, the amount of salt in ocean water may be different in different places. Scientists would not say the ocean is completely homogeneous. Water samples taken from 50 feet below the surface and from 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:



PROPERTIES OF MATTER

Scientists sort matter by its physical and chemical properties. These properties also help scientists identify unknown substances. Scientists use their senses or take measurements to identify physical properties. They make observations and perform experiments to identify chemical properties. Specifically, scientists 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, so 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. The chemical reaction for burning requires oxygen to occur. Air can provide oxygen, as can 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. For example, an iron object will form a reddish-brown coating when left outside for a long time because it 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!

NOTES

STATES OF MATTER

Matter can also be classified based on its state or phase. The most familiar states of matter are solids, liquids, and gases. For example, ice, water, and water vapor are all H_2O in different physical states. As heat is added or removed, the matter may undergo a change of state or a phase change (see the section on Physical Changes).

SOLIDS: have a definite volume and a definite shape. For example, 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 more tightly together than liquid or gas particles. However, the particles are still moving slightly. They vibrate or move back and forth in their place.
- The solid state of a substance tends to be denser than its 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/cc at its melting point.
  - One exception is water. Ice floats when it is placed in liquid water. 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 more quickly from a solid to a liquid when heated above their melting point than an amorphous solid does. 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 a 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 that consists mainly of silicon dioxide (SiO_2). Glass' randomly arranged structure is the reason that glass is transparent. Its structure is easier for light to penetrate than the repeating pattern of a crystalline solid.
  - Wax, rubber, and many polymers, including polystyrene, are amorphous solids (see the subsection on Polymers from *Chemistry Concepts in Action*).

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 SiO_2 in glass has some type of structure but not a specific, repeating one. Therefore, glass is still considered an amorphous solid.

LIQUIDS: have a definite volume but no definite shape.

- A liquid will take the shape of its container or the part of the container it fills.
- A liquid cannot change its overall volume.
- The particles that make up liquids are in constant random motion and move more than 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 closer together than gas particles.
- **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 lower viscosity than honey. When you pour water from one container to another, it flows more quickly than honey does.
  - The ability of a material to flow is related to the strength of the interactions between the liquid molecules. The stronger the interactions, 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. The strong attraction of molecules at the surface of the liquid brings the molecules closer together and 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 to minimize surface area.

Quick Fact

A sewing needle is denser than water. However, when the needle is placed carefully on its side, it will remain on the water's surface because of surface tension.

– 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.

Quick Fact

Many people believe that the water strider bug can "walk" on water purely because of surface tension. However, new research shows there is more to it. The water strider's legs are covered with microscopic hairs that trap tiny air bubbles. The trapped air allows the bug to "float" across the water's surface.

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_2) and oxygen (O_2). Approximately 78% of the air around us is N_2. About 21% of the air is O_2. The remaining 1% includes argon, CO_2, water vapor, and other gases.

Quick Fact

A **fluid** is any substance made up of molecules that flow or move freely. A fluid easily changes shape when a force is applied.

Liquids and gases are fluids. Plasmas are fluids as well (see page 38).

- 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 have weaker attractions between them than do liquid or solid particles, which allows them to move about quickly in random directions and over larger distances. They are also more spread out than liquid particles and can travel farther without hitting one another.
- Because of the extra space between the particles, gases are easily compressed.
- **Effusion** is the movement of gas particles through a small hole in a container from an area of high pressure to an area of low pressure.
  - **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.

Quick Fact

A balloon filled with helium gas will deflate over time as a result of effusion. This process can be slowed down by coating the balloon with a thin layer of metal. This is why special birthday or get well balloons usually have a silvery color. The metal coating is made with aluminum.

EXAMPLE:

Two balloons are filled to the same size with different gases. One is filled with oxygen gas. The other is filled with hydrogen gas. Without being disturbed, the hydrogen 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. Particles are always in random motion because of their kinetic energy, and are more likely to stay in an area with fewer particles once they are there.
  - During diffusion, particles leave highly concentrated areas and enter less concentrated areas until the particles are spread evenly throughout the area. Particles will continue to move, but overall they will be evenly spread throughout the container.
  - Diffusion of particles depends on the concentration of like particles, not the overall concentration of particles in a container.
  - The particles of fluid substances can undergo diffusion.

Quick Fact

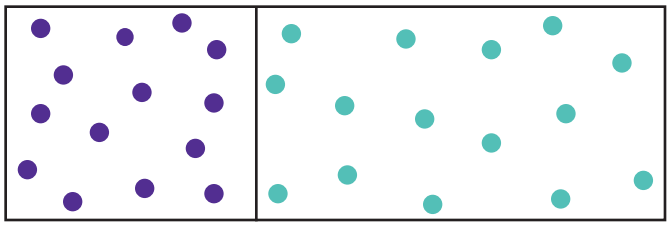
Osmosis is the diffusion of water across a semi-permeable membrane (a membrane that allows some ions or molecules to pass through, but not others).

Osmosis is an important biological process because it allows water to pass in and out of cells.

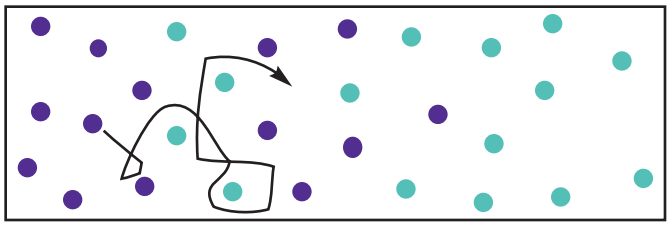
EXAMPLE:

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.

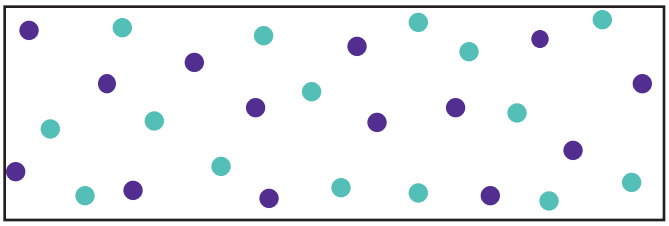
The process of diffusion is illustrated below:



The particles of two fluids are separated by a barrier.



With the barrier removed, the particles begin to diffuse to the other side. The arrow shows the random motion of a particle from a higher concentration to a lower concentration.



The two fluids have reached equilibrium—each is evenly spread throughout the container.

– Concentration, temperature, and the size of particles can also affect the rate of diffusion.

- In general, particles will diffuse more quickly at higher temperatures. At higher temperatures, particles have more kinetic energy and move more quickly. 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. For example, in 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 particles diffuse more slowly.

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

- Plasma is the most abundant phase of matter in the universe. In this phase, electrons have been stripped from the nucleus and float around freely within the material.
- Because the positive and negative charges in plasmas move somewhat freely, plasmas are able to conduct electricity and respond strongly to electric or magnetic fields.
- Plasma is created in high-energy situations. For example, the extreme heat associated with lightning and the interiors 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.

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?

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. As a substance is heated, the particles in that substance move faster. When the particles speed up enough to break the attraction between molecules holding them together as a solid, the particles move freely past each other as a liquid.

- Once a solid begins to melt, its temperature will remain the same until all of the solid changes to a liquid.

EXAMPLE:

At low temperatures (0 °C or below), water molecules have 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.

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. The salt disrupts the bonds between water molecules, making it more difficult (requires more energy to be removed) for water to form the crystalline structure of ice. Roads are salted or sanded in cold weather to prevent ice from forming.

EXAMPLE:

A bottle of juice at room temperature can be cooled by placing it in the refrigerator. Since the refrigerator is lower in temperature, energy will leave the juice. This makes the juice cooler. To cool the juice very quickly, it could also be placed in the freezer. However, if too much energy leaves the juice, it will become a solid.

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 gets smaller as time passes.

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.

- **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 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, which allows them to 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.
- Boiling occurs when the vapor pressure of a liquid equals the surrounding air 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, or the boiling point at sea level.

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. People living high on a mountain sometimes 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. The dew point indicates the temperature at which air is saturated with water vapor and condensation begins to form.

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

Quick Fact

Condensation is the reason the windows inside your house get foggy on a cold day. Tiny water particles in the air come in contact with the cold window. When this occurs, water droplets form on the inside surface of the window. Condensation can also occur on the outside of your windows on a hot summer day. If the air inside your house is cooled by air-conditioning, the water droplets will form outside when they touch the cold surface.

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.

Quick Fact

A comet is a small, icy mass that orbits the sun. Comets have a solid nucleus made of ice and dust. The nucleus is surrounded by a cloudy atmosphere (the coma) and one or two "tails."

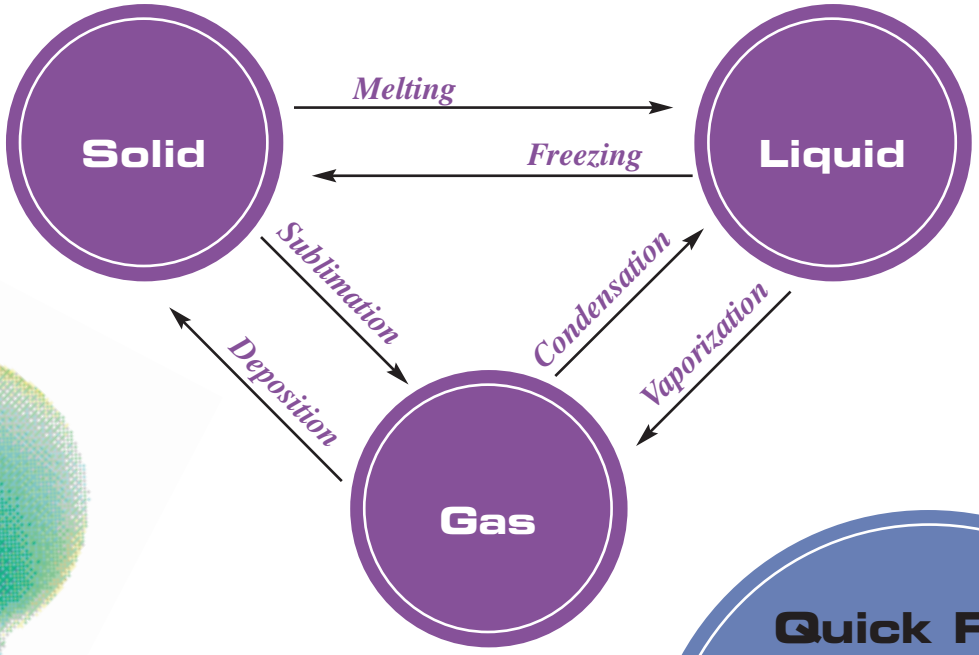
Some comets become visible from the earth for several weeks as they pass close to the sun. As a comet gets closer to the inner solar system, heat from the sun causes some of the ice on the surface of the nucleus to sublime. This sublimation forms the coma. Radiation from the sun also pushes dust particles away from the coma. These particles form a tail called the dust tail. We can see comets because the gas and dust in their comas and tails reflect sunlight.

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.

The following image illustrates the relationship between each of the phase changes:



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.

CHANGES OF STATE—PRESSURE

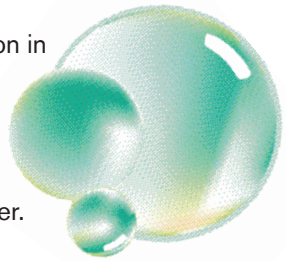
Phase changes occur because a substance has been given energy or energy has been taken away. One way to give a substance energy is through temperature. Another way is through pressure.

EXAMPLE:

Scientists today are still debating why ice is slippery. A common explanation is that the pressure exerted by a person on ice skates creates enough energy to melt the ice, enabling ice skaters to glide along on a thin layer of water that immediately freezes behind them after the pressure is removed. Friction between the skates and the ice also produces heat that contributes to melting the ice. Some scientists argue that there is a layer of unfrozen water on the surface of ice even at temperatures below water's freezing point.

CHEMICAL CHANGES

Chemical change: a change that takes place when atoms of a substance are rearranged. Bonds between atoms in the substance are broken or formed. When a chemical change takes place, the ending substance or substances are different from the starting substance or 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 involve changes in energy.
- 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

Many 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.
- 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 responds 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.

Think About It...

What other forms of energy are there? What kind of energy is used when winding a clock? What kind of energy is produced in power plants?

Quick Fact

Light is an example of electromagnetic energy. Electromagnetic energy is a form of energy that can travel through a vacuum (see the Energy section from *Chemistry Concepts in Action*).

EXAMPLE:

If you put a ball on a shelf it contains potential energy, or 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, or energy of motion, as the ball fell. The energy also changed to sound energy, which is what you hear when the ball bounces.

Quick Fact

Albert Einstein figured out the relationship between matter and energy. He concluded that matter can be changed into energy and vice versa. However, the total amount of matter and energy in the universe doesn't change. He put his idea into the equation: $E = mc^2$.

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 can change 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 an object. The total mechanical energy of an object 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:

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

- 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 an object's mass, height, and the gravity affecting it, 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, like a ball on a shelf. When a chemical substance undergoes a reaction it may lose some energy, like a ball losing potential energy as it falls from the shelf. In other reactions, the chemical may gain some energy. For example, a ball would gain potential energy if someone put it back on the shelf.

Many chemical reactions involve the absorption or release of thermal energy.

- **Exothermic change**: a change that gives off energy, releasing energy to its surroundings.
  - Any burning reaction is an exothermic reaction because it releases thermal energy or heat. These reactions include lighting a match and burning coal or other fuels.
- **Endothermic change**: a change that takes energy from its surroundings.
  - 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 or when heat is applied. Therefore, the formation of nitrous oxide is an example of an endothermic chemical reaction.
- Thermal energy is transferred from warmer areas to cooler areas.

Quick Fact

While temperature and thermal energy are related, they are not the same thing. Remember, temperature is a measure of the average kinetic energy of particles in a substance. Thermal energy is the total kinetic energy of all particles in a substance. Thermal energy focuses on the internal energy of the substance related to temperature.

PHYSICAL AND CHEMICAL SEPARATIONS

Matter can be classified as either a pure substance or a mixture. 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.

Quick Fact

Different-sized solids can be separated from one another by screening or sieving. A *sieve* is a useful tool for separating rocks from sand. It traps the rocks and lets the sand go through.

Filtration can be used to separate mixtures on a molecular level, too. In your body, your kidneys use filtration. They separate big molecules, like proteins, from your blood.

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 differences in size between the particles that make up different parts of the mixture.

- 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 solid 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.

Quick Fact

Another process similar to filtration is "reverse osmosis." As its name suggests, think of it as the opposite of osmosis. See page 37.

Reverse osmosis occurs when a solvent moves across a semi-permeable membrane from an area with a high solute concentration to an area with a lower solute concentration. The movement in this direction is a result of pressure. Reverse osmosis is often used to remove the salt from sea water.

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 use chemical properties to separate parts of the mixture and 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 **precipitate**.
- 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 (Pb^{2+}) has a way of getting into the water supply and needs to be removed because it is hazardous to human health. Chemists can accomplish this by adding sulfides (S^{2-}) or sulfates (SO_4^{2-}). These substances will combine with the lead to make a new solid compound.

$$Pb^{2+} + S^{2-} \rightarrow PbS$$

$$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4$$

Once the solid compound is formed, the lead, which is part of the solid compound, can be removed from the water by filtration. 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

SECTION IV:
ATOMIC STRUCTURE

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

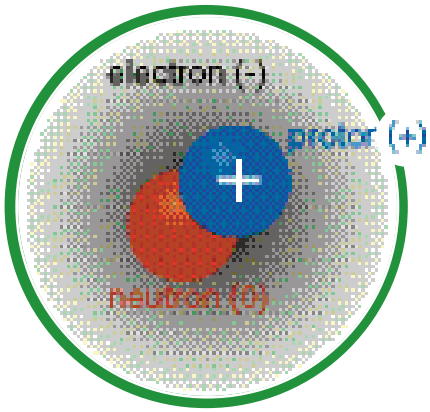
An **atom** is the fundamental unit of an element. It is the smallest particle of an element that retains the element's chemical properties. For example, if a scientist cuts a piece of aluminum down until it can't be divided anymore, it is still aluminum. The smallest particle that still maintains that identity is classified as 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 comprised 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 in the space outside the nucleus. Some images show electrons as small particles that follow a well-defined path, or orbit, around the nucleus, but this is misleading. Electrons actually move around the nucleus in cloud-like regions called electron clouds (see the subsection on Electron Configuration).
  - Electrons have a mass that is 1,836 times lighter than protons and neutrons. 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 electric 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 (+) and 1 electron (-). You can see this by adding up all the charges:

1 proton (+) + 1 neutron (0) + 1 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 develop the theory of atoms. We know very little about his life and work, but 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, but 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.

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 known as 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, which 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*).

HISTORY: **NIELS BOHR** (1885–1962)

Niels Bohr, a Danish scientist, was a student of Ernest Rutherford. In 1913, Bohr expanded on Rutherford's atomic theory. He proposed that electrons have only a specific amount of energy and travel in certain orbits based on that energy level. Therefore, electrons with higher energy traveled in the larger, outer orbits. He also suggested that the outer orbits determined the atom's chemical properties. Bohr's model is often still used to help illustrate electron energy levels (see the subsection on Electron Configuration).

In 1922, Bohr was awarded a Nobel Prize for physics for his work on atomic structure.

Through advances in science and technology, scientists have been able to study atoms using particle accelerators. Two types of particle accelerators are cyclotrons and synchrotrons.

- In these accelerators, particles can move at high speeds that cause atoms to break apart upon impact.
- Particle accelerators have led to the discovery of more than 100 different subatomic particles, including quarks. **Quarks** are small 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 $+^{2}/_{3}$. Down quarks have a charge of $-^{1}/_{3}$.
    - A proton contains two up quarks and one down quark, giving protons have a total charge of +1.
    - A neutron is made of two down quarks and one up quark, giving neutrons have a charge of 0.

MOLECULES

When two or more atoms interact with one another, they may form a larger unit called a molecule.

Molecule: a neutral particle composed of two or more atoms held together by chemical bonds. A molecule can be made up of similar or different types of atoms.

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.

Quick Fact

A single molecule of water is extremely small and cannot be seen by the naked eye, but we can actually estimate how many water molecules are in a drop of water. (See the subsection on Chemicals by Mass from *Chemistry Connections*.)

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, which means it only has one proton in its nucleus.

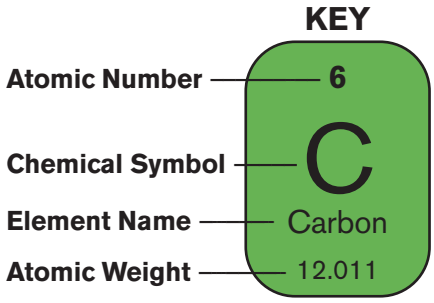
Mass number (atomic mass number): the number of protons plus the number of neutrons in an atom's nucleus.

Quick Fact

Scientists use an instrument called a mass spectrometer to figure out what elements are in a sample. First, the mass spectrometer ionizes (charges) the atoms in the sample. Then, once the atoms have a charge, scientists can use electric and magnetic fields to separate the atoms. This process allows the "mass spec" to determine the mass of the atoms, which allows scientists to determine what atoms are in the sample.

CHEMICAL SYMBOLS

Chemical symbols are used to represent elements on the periodic table. Each element has its own symbol that is different from all other chemical symbols. These symbols are made up of either one or two letters (except for some new elements that have not yet been named). 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 oxygen is O. The symbol for calcium is Ca. Chemical symbols are included on the periodic table as shown below.



IONS

The total number of protons in an atom of an element never changes, but atoms can gain or lose electrons.

- Protons have a positive charge and electrons have a negative charge, so 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.

- Ionization (formation of ions) happens when electrons are gained or lost. Therefore, the number of protons and neutrons does not change when an ion is formed from an atom. The atomic number and atomic mass number of each ion stays the same.

The image below shows three forms of hydrogen: the electrically neutral atom and two ions.*

The hydrogen atom (H) **A hydrogen anion (H^-)** **A hydrogen cation (H^+)**

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

ISOTOPES

The number of protons of an element is the same for all atoms of that element, but the number of neutrons in those atoms can vary.

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

- Isotopes of an element have the same number of protons (atomic number) but a different number of neutrons in the nucleus. The mass number for each isotope of an element is different.

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:*

Quick Fact

The word "isotopes" comes from the Greek words "iso" (same) and "topos" (place). Any isotope of a certain element can take the same place in a chemical reaction. The chemistry of an atom does not normally depend on how many neutrons it has.

Hydrogen (Protium)
Atomic number = 1
Atomic mass number = 1

Deuterium
Atomic number = 1
Atomic mass number = 2

Tritium
Atomic number = 1
Atomic mass number = 3

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

H

HYDROGEN

Atomic #1

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.

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 (H_2) is colorless, odorless, and also highly flammable. Hydrogen gas 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 is used in the hydrogen bomb.

Hydrogen is also a fuel for the stars because it is 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, which allows stars to shine for billions of years.

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 abundant each isotope of an element is on the earth.
- This weighted calculation explains why an element's relative atomic mass is not a whole number.

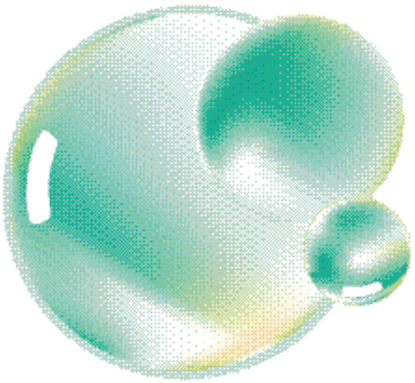
EXAMPLE:

Chlorine has two primary and stable isotopes: chlorine-35 and chlorine-37. The number after the element's name is the atomic mass number. Chlorine-35 has a mass number of 35, and a combined total of 35 protons and neutrons. Chlorine is found in nature as chlorine-35 about 75 percent of the time. This means that 75 out of every 100 chlorine atoms are 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 and gave it 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. This isotope has a mass number of 12 and is called carbon-12. Carbon-12 is the most common isotope of carbon. 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

SECTION V:
THE PERIODIC TABLE

OBJECTIVES

- Locate elements on the periodic table.
- Distinguish between the different elemental groups on the periodic table.
- Utilize the periodic table to describe properties of elements and electron configuration.

In the 1860s, Russian chemistry professor Dmitri Mendeleev collected information about each of the known elements for his book, *Principles of Chemistry*. He used this information to organize the elements in order of their atomic weights and noticed certain patterns of chemical reactivity and physical properties. Based on these patterns, he grouped the elements into rows and columns and created what we now 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 gaps because of missing elements that 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 is that he was able to predict the presence and properties of several new elements. He made these predictions based on the gaps in his table.

The big difference between Mendeleev's table and today's is that today's table is organized by increasing atomic number, while Mendeleev's used increasing atomic weight.

- At first, atomic numbers were based on an element's position on Mendeleev's periodic table and therefore 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, which caused discrepancies in patterns. 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.

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.

Quick Fact

Some chemical symbols are based on the Latin name of the element. For example, the Latin name for gold is "aurum." The Latin name for lead is "plumbum."

Quick Fact

In 2013, elements 114 and 116 were officially named flerovium and livermorium. They were named in honor of the two labs that created them.

ARRANGEMENT OF ELEMENTS ON THE PERIODIC TABLE

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

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, so members of the same group generally participate in the same types of reactions.
- Members of the same group usually have very similar chemical 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. Moving 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 energy levels, but they differ in how they are filled. As explained on page 72, the energy levels of electrons are represented by "shells."
- Some periods on the table are much longer than others. Look at the sixth and seventh periods and notice that 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 metals, nonmetals, or semi-metals.

- Metals are found mainly on the left side of the periodic table.
  - Metals tend to be 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.
  - Nonmetals 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.

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.

ELEMENTAL GROUPS

GROUP 1 – ALKALI METALS (except hydrogen)

Alkali metals, including lithium, sodium, and potassium, are soft low-density metals with the following characteristics:

- Have low melting points and oxidize (become dull when exposed to air) easily
- 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"
- Are likely to give one electron away to form a bond to reach the very stable, "filled outer shell" state

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 (H_2). Therefore, hydrogen can have characteristics of two groups—one and seventeen. Some periodic tables show it that way.

Na

SODIUM

Atomic #11

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 elemental 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 ($NaHCO_3$). 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.

Quick Fact

Alkali metals and alkaline earth metals get their names because they often form solutions with a pH greater than 7. Solutions with a pH level greater than 7 are defined as "basic" or "alkaline" solutions. (See the Acids, Bases, and pH section from *Chemistry Connections*.)

NOTES

K

POTASSIUM

Atomic #19

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 (K_2O) is called potash. Potassium hydroxide (KOH) 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 salts are electrolytes, substances that conduct electricity in the human body. Electrolytes easily separate into ions in a solution, which enables them to conduct electricity. Other electrolyte ions in the body include sodium, chloride, calcium, and magnesium.

GROUP 2 – ALKALINE EARTH METALS

Alkaline earth metals, including beryllium and magnesium, have the following characteristics:

- 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)
- Have two electrons in their outer energy level, which they tend to give away
- Are found in the earth's crust but not in elemental form because of their reactivity
- Are found in many rocks on the earth

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.

Mg

MAGNESIUM

Atomic #12

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 to cause muscles to contract
  - Is found in 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 human-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 (MgO). Because of this property, magnesium is commonly used in flares.

Magnesium is a component of Epsom salts (hydrated $MgSO_4$). Epsom salts are used to soothe aches and pains.

Ca

CALCIUM

Atomic #20

The name calcium comes from the Latin word "calx," meaning lime. It is found naturally in limestone as calcium carbonate ($CaCO_3$). 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, 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 ($CaSO_4$) is useful for making casts to set broken bones.

GROUPS 3–12 – TRANSITION METALS

Transition metals cannot be divided neatly into individual groups because they have similar properties and characteristics, including:

- Have good thermal and electrical conductivity
- Are hard metals and have very high melting points
- Have low to moderate reactivity

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.

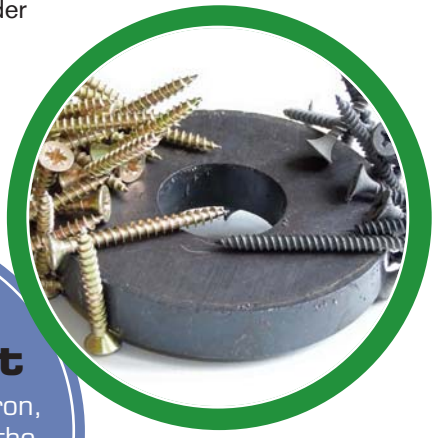
Most elements can only use electrons from their outermost orbital to bond with other elements (see the subsection on Electron Configuration in this portion of the Passport and the subsection on Periodic Trends from *Chemistry Connections*). Transition metals, however, can use the two outermost orbitals. This chemical trait allows them to bond with many different 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. Mercury was previously used as a liquid in thermometers because its low melting point allowed it to measure temperatures below the freezing point of water.



Quick Fact

The transition metals iron, cobalt, and nickel are the only elements known to produce a magnetic field.

Fe

IRON

Atomic #26

Iron is one of the most abundant metals on 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 (Fe_2O_3) and magnetite (Fe_3O_4)
- 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 Fe_2O_3. 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.

NOTES

Zn

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:

- Is a bluish-white shiny metal
- Is used in dry cell batteries
- Is 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 iron. In the presence of air, the zinc oxidizes. When this happens, a coat of $Zn_2(OH)_2CO_3$ 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.

Ag

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 (Ag_2S), 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.

Quick Fact

Silver is a great reflector of visible light, but does not reflect ultraviolet light as well.

Au

GOLD

Atomic #79

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.

NOTES

Hg

MERCURY

Atomic #80

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

Characteristics:

- Is the only metal element that is liquid at room temperature, which is about 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, its use is limited because 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 plastic fillings instead of amalgams.

GROUP 17 – HALOGENS

Halogens, including fluorine, chlorine, and bromine, are nonmetal elements with the following characteristics:

- Exist as diatomic molecules at a normal room temperature—F_2, Cl_2
- 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)

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

Halogens react with metals to form salts. Halogen salts include sodium chloride (NaCl) and calcium chloride ($CaCl_2$).

Quick Fact

The name halogen comes from the Greek words "hals" meaning "salt" and "gennan" meaning "to form or generate."

Quick Fact

A halide is a compound formed by a halogen and another element that has a lower electronegativity (see the subsection on Periodic Trends from *Chemistry Connections*). Many salts are halides.

F

FLUORINE

Atomic #9

Fluorine is very reactive, making it 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). Many 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, a very corrosive and dangerous acid.

Quick Fact

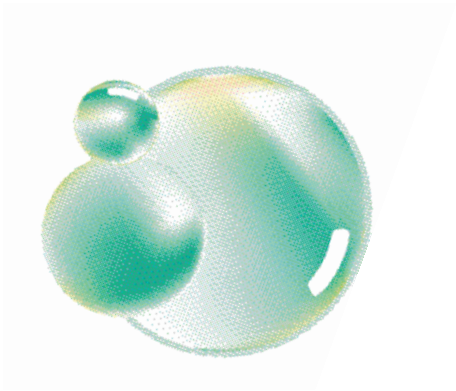
Fluorine is so highly reactive that it forms compounds with krypton, xenon, and radon—elements that were considered to be unreactive for many years.

Quick Fact

Pure fluorine's reactivity makes it difficult to store. It attacks glass and causes most metals to burst into flames.

Quick Fact

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



Cl

CHLORINE

Atomic #17

The name chlorine comes from the Greek word "chloros" meaning "pale green." In 1774, Karl Wilhelm Scheele first produced chlorine 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 including paper products, textiles, petroleum products, medicines, disinfectants, pesticides, food, paints, and plastics.

GROUP 18 – NOBLE GASES (INERT GASES)

Noble gases, including helium, neon, and argon, are colorless, odorless gases at room temperature with the following characteristics:

- Have low boiling points
- Have almost no reactivity. The term "inert" means inactive, so noble gases are often referred to as inert gases because of their low reactivity
- 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

Quick Fact

Noble gases were known mostly as "inert gases" until it was discovered that xenon reacts with fluorine and oxygen.

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, which is why 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 one or more noble gases. When an electric current is passed through the tube, the gas 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.

He

HELIUM

Atomic #2

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"!

Ar

ARGON

Atomic #18

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
  - Argon prevents oxygen from corroding the hot wire filament inside light bulbs.

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.

Quick Fact

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

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 (lanthanoid series) are the inner transition metals from period 6. They are named after the first element in the series, lanthanum, and share the following characteristics:

- Are shiny, silvery-white metals
- Are chemically similar to each other; their properties differ slightly 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

Quick Fact

Scandium and yttrium have properties similar to the lanthanides. Therefore, they are sometimes treated as lanthanides.

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.

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 (actinoid series) are the inner transition metals from period 7. They are named after the first element in the series, actinium, and share the following characteristics:

- 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.

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.

ELECTRON CONFIGURATION

An element gets its chemical properties mainly based on its 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 phenomenon 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 so 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 circular 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, so they are described as being found "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.

Scientists of the 20th century studied how light interacts with electrons, which helped them learn more about the location of electrons in atoms. The information they discovered is just the beginning. Scientists still have much to learn and confirm about atoms.

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 an electron at the same time. The best way to do this is to represent the probability of finding an electron of a given energy and momentum within a given space.

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 **principal 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 is at a higher energy level 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.

Quick Fact

"Shell" is simply a term that some people use instead of principal quantum number. If electrons have the same principal quantum number (the same energy level), they would say that those electrons are in the same shell. However, remember that electrons are not actually in shells. They are in orbitals.

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 is likely to go. You are not likely to find a couch potato at 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.

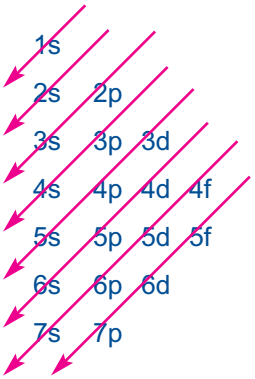
Each orbital can hold up to two electrons. Based on the previous example, we know that an atom cannot have more than 18 electrons with energy level 3 because there are nine orbitals that hold two electrons each. The example also tells us that there are different numbers of each type of subshell.

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

Subshell Type	Number of Orbitals	Maximum Number of Electrons
s	1	2
p	3	6
d	5	10
f	7	14

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.

Quick Fact

Notice that electrons fill in the 4s orbital before the 3d orbital. The 3d state is at a higher energy level than the 4s even though the 3d state has a lower principal quantum number. There is no simple explanation here, but it has to do with how an electron interacts with all the other electrons already in the atom. There are also some exceptions to this when the different levels are filled.

Again, you can think of this in terms of people. A mountain climber might have the energy needed to climb Mount Everest. However, s/he may stay at the base camp if there are already too many people at the top.

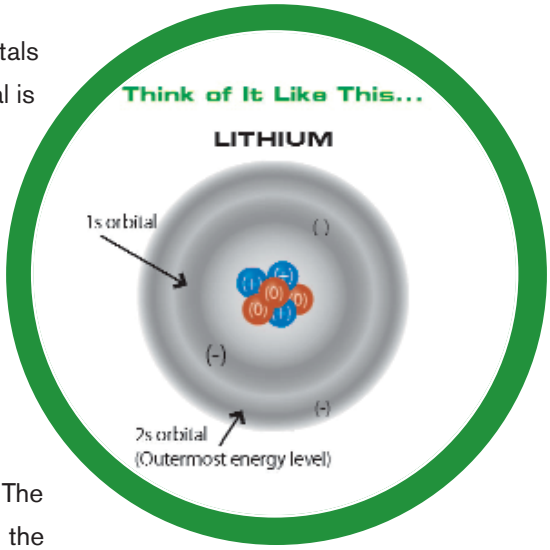
As shown above, the order for filling in the orbitals and energy levels is:
1s, 2s, 2p, 3s, 3p, 4s, 3d, 4p, 5s, etc.

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.

Scientists use a certain format to write an atom's electron configuration. The electron configuration below represents the element helium.

$$1s^2$$

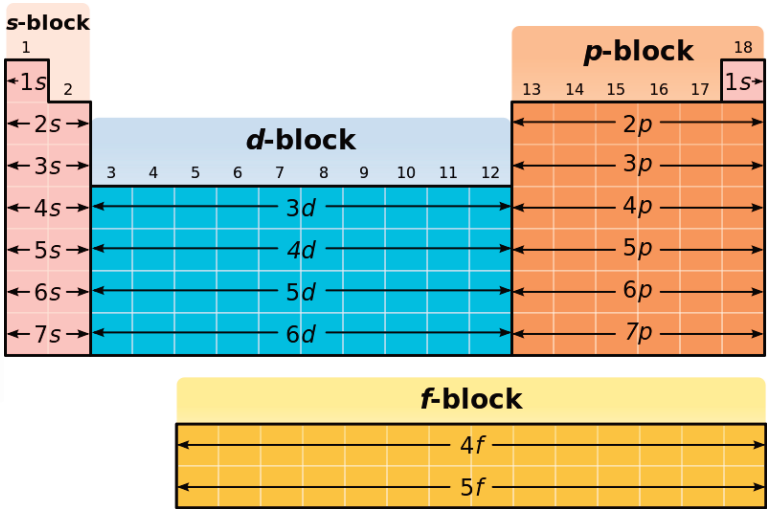
- The first number is the principal quantum number. Again, it is the electron's energy level. In this case, the "1" represents the first energy level, which tells us that the electrons of helium occupy the first energy level of the atom.
- The letter refers to the type of orbital. In this case, the "s" 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 subshell. 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 (with spherical shapes). Also notice that the second energy level orbital is larger and farther from the nucleus. The electron configuration for lithium is: $1s^2 2s^1$.

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.

This trend continues with all elements. The electron configuration of an element or ion can be determined by its location on the periodic table. The way the periodic table is arranged indicates the specific order in which the electron energy levels are filled, going from left to right across each row as pictured below (compare to diagram on page 73). For example, the electron configuration of argon, located on the right in the 3p section, is $1s^2 2s^2 2p^6 3s^2 3p^6$. All of the orbitals in the first row are filled, as are all of the orbitals in the second and third rows. The electron configuration of chlorine, located to the left of argon, is $1s^2 2s^2 2p^6 3s^2 3p^5$. Each section of the periodic table below is labeled with the orbital sublevel of the elements' valence electrons. Also notice that elements in the same groups have similar electron configurations.



SECTION VI:
LABORATORY EQUIPMENT

OBJECTIVES

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

BASIC EQUIPMENT

The following are some examples of common laboratory equipment that scientists use while performing experiments:

Beaker: a wide, open container with a flat bottom made of glass or plastic.

- A beaker is a simple container used to mix, heat, or hold substances.
- A *graduated* beaker can give approximate measurements of liquid volumes. The term "graduated" means it is marked with measurements.
- The top rim of the beaker usually has a *lip* and 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 rounded base. Flasks can be used to measure, heat, or store liquids.

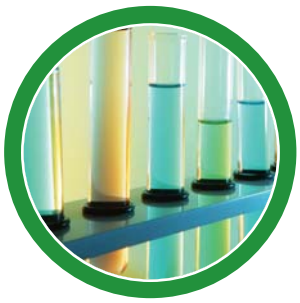
- The neck of the flask allows scientists to either attach a clamp to it or place a stopper in it.
- **Erlenmeyer flask:** a flask with a cone-shaped base. It is often used during a filtration or titration process (see the Laboratory Analysis section from *Chemistry Concepts in Action*).
  - The wide surface area of the flask's bottom allows liquids to be heated quickly.

- **Florence flask (boiling flask):** a round flask that may have a rounded or flat-bottomed base.
  - A liquid contained in a Florence flask will heat evenly because the round shape spreads the heat around the flask.
  - Florence flasks tend to be stronger than other flasks. They are often used to boil liquids for distillation processes and must be able to withstand extreme temperature changes.

- **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 volumetric flask has a single line around the long neck marking the point to where the flask should be filled. Volumetric flasks are used to accurately measure liquids to a fixed volume or to create solutions of fixed volumes.

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

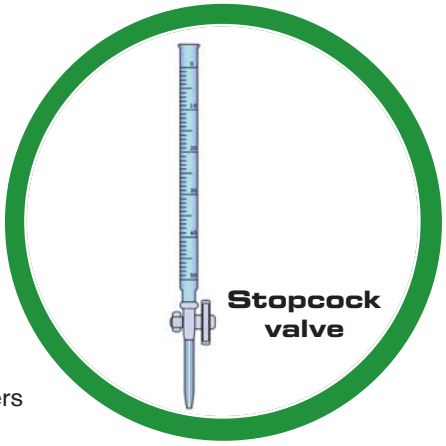
- Test tubes are used to hold or heat small amounts of a substance during laboratory experiments.
- Test tubes are usually held upright using clamps or special test tube holders.



MEASURING LIQUID VOLUMES

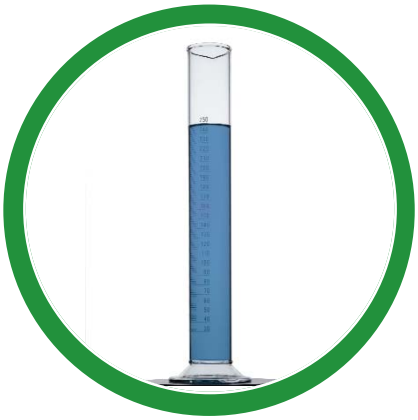
Buret (burette): a long glass cylinder used to accurately measure and dispense a specific volume of liquid. The cylinder is open at the top, while the bottom comes together into a tip from which the liquid flows. A *stopcock valve* is attached to the bottom, above the tip, which controls the amount of liquid that flows from the buret.

- Burets are often used for titrations (see the Laboratory Analysis section from *Chemistry Concepts in Action*), where scientists place an Erlenmeyer flask directly below the tip of the buret and then control the amount of liquid released from the buret.



Graduated cylinder: a tall, cylindrical container used to measure the volume of a liquid.

- It was named a "graduated" cylinder because it has markings along the side to indicate how much volume is being measured. Graduated cylinders are made in many different sizes, 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 concave (inward) curve at the liquid's surface is called the **meniscus**.
  - A meniscus is created because the liquid's particles are attracted to the walls of the container.
  - Scientists measure the volume of a liquid by reading the bottom of the meniscus at eye level (see the image below).

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, 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. 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. If the solid reacts with water, they may need to choose another liquid for the measurement. First, they add a certain amount of water or other liquid to a graduated cylinder and record its volume. Then, they carefully drop the solid into the cylinder. After the solid is submerged, they take the new volume 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, but the measurement may not be as accurate.

MEASURING MASS

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

Triple-beam balance: a device used to measure the mass of an object by comparing the objects' mass to the mass of predetermined "weights" known as riders.

- The balance has a pan connected to three beams marked with certain measurements, each carrying a different rider with a known mass. Attached to the other end of the beams is a pointer, which shows when the device is balanced.
- To measure the mass of the object on the pan, the riders are moved across the beams until the pointer shows that the riders and the object on the pan are balanced. 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, which measure with great precision and accuracy.

- The measuring pan of an analytical balance is enclosed inside the device to prevent dust from collecting on the pan and to prevent air currents in the room from affecting the measurement.

Scientists often measure an empty container first and then measure the container with a substance inside. The mass of the substance can then be determined by subtraction.

- 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 that expands as it is heated. The heated fluid is pushed up the tube. The tube is so thin that 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.

- Digital or electronic 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.
  - 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, which measures 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.
  - The bimetallic strip is generally attached to a pointer. As the metals bend, 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.

EXAMPLE:

Most bimetallic strips are made of copper and steel. Copper may be on top and steel on the bottom. Copper will expand more when heated, causing the strip to bend downward. As it cools, the copper will shrink more quickly than the steel, so the strip will bend upward.

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.

HISTORY: **THERMOMETER**

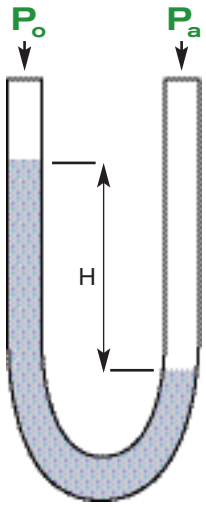
In 1593, Galileo Galilei invented a water thermometer. Water freezes at 0 °C, so the thermometers could not measure temperatures below the freezing point of water.

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 has a freezing point below the freezing point of water. Mercury was replaced with alcohol because it is dangerous to humans. If a mercury thermometer breaks it can be a hazard, so alcohol is a safer alternative.

MEASURING PRESSURE

Manometer: a device used to measure the pressure of a fluid. Manometers often measure pressure based on differences in the height (H) and position of a column of liquid in a "U" tube.



P_o = reference pressure (open to atmosphere)

P_a = test pressure

- 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.

Barometer: 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 while he was investigating vacuums.

- He determined that the height of mercury in a tube placed over a dish of mercury was only $^1/_{14}$ the height of water in a tube placed over a dish 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 and 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.

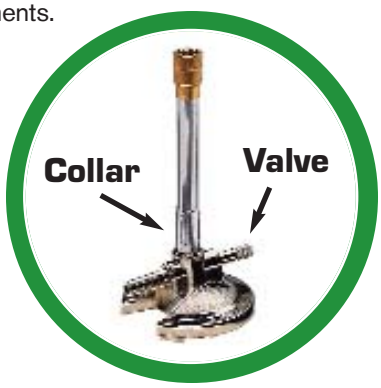
TRANSFERRING LIQUIDS

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

- Liquid is drawn up into a pipette by suction. A vacuum is created in the pipette. When the pipette is placed into a liquid, the vacuum creates 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, and 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.
  - These pipettes come in different sizes, usually ranging from 5 mL to 50 mL.

HEATING MATERIALS

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.
- 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.

Many laboratories prefer to heat substances using an electric source, such as a hot plate or temperature-controlled oven, rather than a flame.

HISTORY: **ROBERT BUNSEN** (1811–1899)

In 1855, Robert Bunsen improved the heating burner that is named after him, although 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.

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

SECTION VII:
LABORATORY & CHEMICAL SAFETY

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, but can also be hazardous if mishandled or misused. It is very important that anyone using chemicals understands how to safely store, handle, and use them.

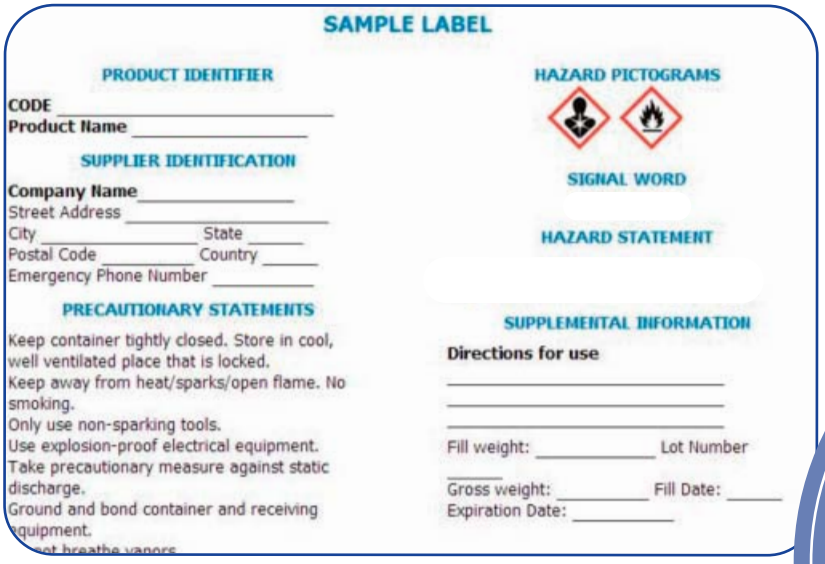
WHERE TO FIND CHEMICAL SAFETY INFORMATION

Product container labels include important information about storage and handling, as well as 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 displaying a hazard rating from 0 to 4. Each section of the safety diamond has a specific color associated with a particular type of hazard. 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, which in turn indicates the amount of protective equipment a person needs in order to safely work with the 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, indicating that the chemical should be kept 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 needed to safely handle that chemical. The image below shows what a label might look like*.



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 2015, all chemical labels were required to have basic information about how to safely handle and work with those chemicals.

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 and 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.

*Image Source: "Hazard Communication Standard Labels." *Occupational Health & Safety Administration.* U.S. Department of Labor. August 18, 2014. www.osha.gov/Publications/HazComm_QuickCard_Labels.html

Anyone can benefit from having this important product information available. SDSs provides information about any necessary precautions when using products, but are also meant to provide general information about different chemicals and substances. SDSs are available for most substances, including common household cleaning products, gasoline, pesticides, certain foods, drugs, some office and school supplies, and even water.

EXAMPLE:

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

WARNING SYMBOLS

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 and they ultimately help make sure that people use chemicals in a safe and responsible manner. If you see these symbols, pay attention, follow instructions carefully, and look for other information about the chemical.

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.

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 when special care is needed to avoid causing any harm.

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.

The *flame* symbol indicates the presence of a flammable substance. A flammable substance is one that easily ignites. When working with a flammable substance, be sure to avoid anything that could start a fire, such as electrical sparks or a hot surface. Flammable substances include gasoline, propane, and ethanol.

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 these 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.

Quick Fact

These warning symbols are used as part of the Globally Harmonized System of Classification and Labeling 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 toxic chemicals with 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 depending on contact.

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. As with the other health symbols mentioned above, contact may be detrimental to human health and may require medical help.

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 and could carry harmful diseases.

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 yourself 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.

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.

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.

The *eye protection* symbol means that safety goggles or other eye protection is required. Different types of eye protection can be worn depending on different safety measures. 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, such as a face shield, is required. Face shields protect your entire face from splashing liquids or other potentially hazardous materials.

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, to follow safe practices, and to understand all potential hazards.

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, specific safety instructions for the place you are working and for the materials you are using should always be followed.

- Always read through directions and SDSs completely before beginning an experiment.
- Avoid touching your eyes or mouth when working in the laboratory.
- Keep your face away from the opening of a container that holds chemicals.
- Wear the proper protective gear and clothing.
- When mixing chemicals, follow the instructions carefully.
- Work with other people, never work alone.
- Wear safety goggles to protect your eyes.
- Know where safety equipment is located.
- Do not eat or drink in the laboratory.
- Be careful when working with sharp objects like scissors or knives.

When storing chemical substances:

- Label all storage areas and containers clearly.
- Avoid storing chemicals in areas that are difficult to see or reach.
- Reactive chemicals should never be stored near each other.

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 to prevent contamination.
- Use a glass stirring rod to pour a liquid into a beaker to prevent liquid from 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.
- When an acid must be mixed with water, always add the acid slowly to water.

When handling glassware:

- Do not use glassware that is chipped or cracked.
- Do not place hot glassware directly on a table.
- Allow plenty of time for hot glass to cool before touching it.

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.
- Do not let electrical cords lay across work spaces.
- Never reach across an open flame or other heating device.
- Never look into a container that is being heated.
- Never heat a closed container; pressure may build up and cause the container to break or burst apart.
- Do not bring any substance into contact with a flame.
- Use tongs when removing glassware or other containers from a heat source to avoid burns.

Quick Fact

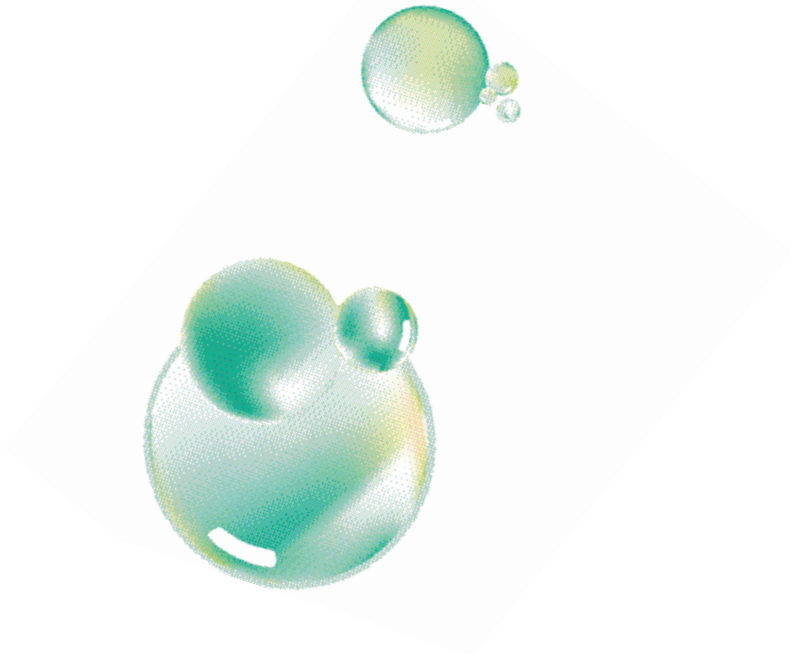
Crucibles are often used to melt metals, to dry powders, or to accomplish other high-temperature tasks. Crucibles are special high-temperature porcelain containers.

Tongs should be used to hold onto hot containers or crucibles.

Special "test tube holders" should be used to hold a test tube over the flame of a Bunsen burner.

When cleaning up, be sure to:

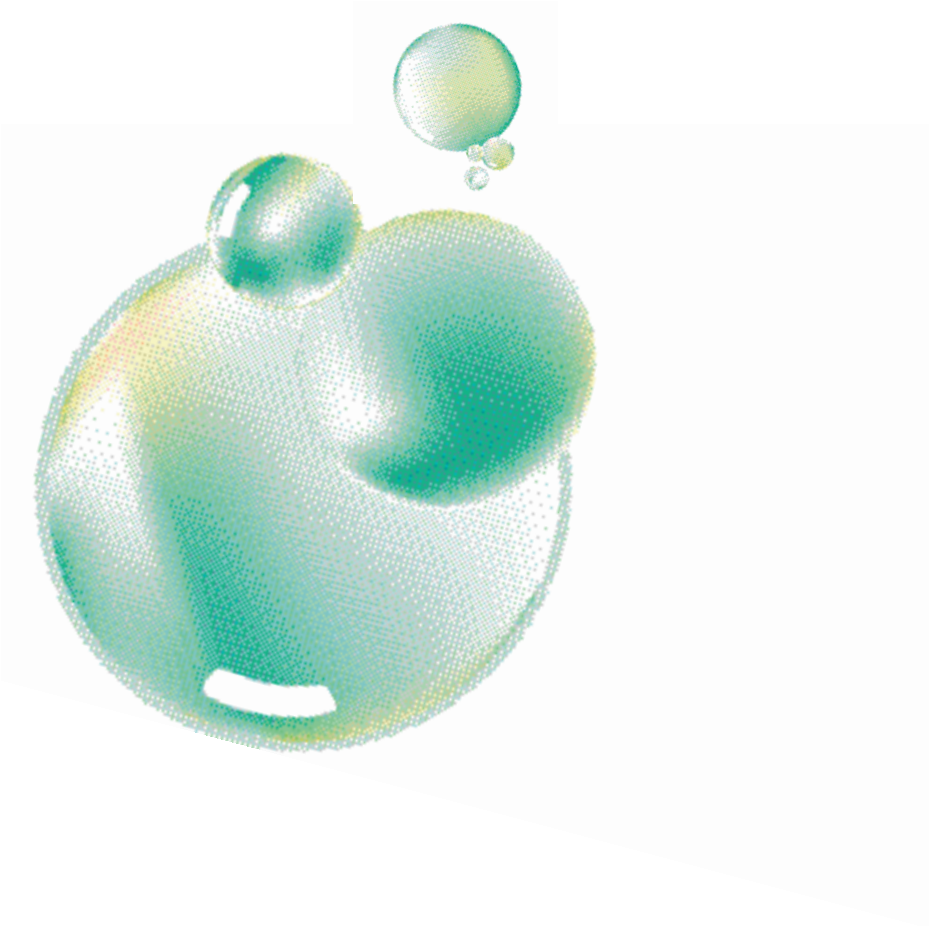
- Turn off all heating instruments and disconnect any electrical equipment.
- Return all materials to their proper places.
- Avoid simply disposing of chemicals down the drain.
- Clean and dry your work area.
- Wash your hands with soap and water after completing an experiment.



NOW YOU'RE READY FOR THE

CHALLENGE

GOOD LUCK!



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