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TABLE OF CONTENTS

You Be The Chemist Challenge Study Materials

I. SCIENCE—A WAY OF THINKING

II. MEASUREMENT

III. CLASSIFICATION OF MATTER

IV. ATOMIC STRUCTURE

V. THE PERIODIC TABLE AND FORCES OF ATTRACTION

TABLE OF CONTENTS

You Be The Chemist Challenge Study Materials

VI. CHEMICAL BONDING AND FORMULAS

VII. CHEMICAL REACTIONS

VIII. RADIOACTIVITY AND NUCLEAR REACTIONS

IX. LABORATORY EQUIPMENT

X. LABORATORY & CHEMICAL SAFETY

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.

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. 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. There are many ways to explore science, so different books, websites, and documents describe the scientific method and scientific inquiry in different ways. The scientific method includes the following basic practices, which are all a part of scientific inquiry:

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

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

OBSERVATION

Scientific inquiry usually begins with an observation. Scientists explore and collect information with their senses using smell (wafting), sight, sound and touch and ask questions that they would like to answer. The sense of taste should NOT be used in scientific inquiry involving unknown substances. Scientific questions guide scientists in their research and can usually be answered by collecting evidence. A scientific question must have a specific correct answer that is provable through direct observation or scientific experimentation.

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?**

RESEARCH

After asking a question based on their observations, scientists do background 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. Scientists will research the methods used in past research to help inform their own experimental design and to learn from the experiences of other scientists.

Scientists do research on the topic they're investigating throughout the entire scientific inquiry process. After they have completed their own experiment, they may conduct research to compare their results to the results from other, similar experiments.

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

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.

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 ice cube trays filled with hot and cold liquid water are put in a freezer, the 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** - page 6). 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. Scientists frequently design and conduct an experiment and then go back and conduct additional research before changing their experimental design.

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 collected throughout the scientific inquiry process so that it can be analyzed to determine results and referenced to support conclusions. 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 make sure that they collect accurate data so their results will be trustworthy. In addition to carefully collecting data in a controlled experiment, scientists must repeat an experiment multiple times to ensure they can obtain the same results each time before those results are considered reliable by the scientific community.

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. You also make a note that you should compare the results to 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 organize the data in a graph that illustrates the freezing time in relation to the starting temperature. You also repeat the experiment to make sure that your results can be reproduced, which indicates that others can trust your data.

CONCLUSION

If the hypothesis was testable and the experiment gives clear data, a conclusion can be made based on data. A **conclusion** is a statement that tells whether or not the hypothesis was correct and explains how the data and observations support or disprove the hypothesis.

- If the data support the hypothesis, then the hypothesis is considered to have been verified.
- If the data do not support the hypothesis, then the hypothesis is considered to have been refuted.

Scientists learn something from both valid and invalid hypotheses. A new hypothesis can be made or adjusted if they want to continue investigating the scientific question. 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?

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."

DESIGNING AN EXPERIMENT

Scientists need to figure out a plan for testing a hypothesis. To do this, they design an experiment. Scientists have to be careful to change 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 determine which factor actually impacted the results. When designing an experiment, scientists must 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 in the experiment the same while changing only the initial 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 collect reliable data.

VARIABLES

Factors that can be changed and controlled in an experiment are known as variables. In an experiment, scientists can see how changes they make to the independent variable affect the dependent variable.

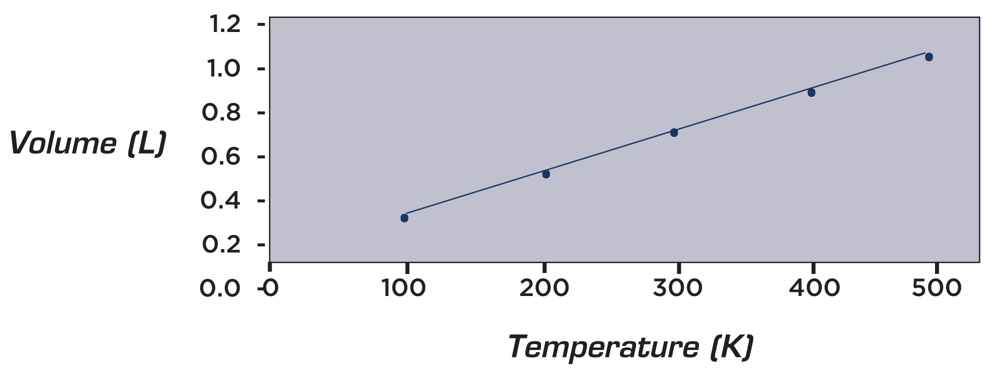
- **Independent variable:** the variable scientists change in the experiment. This is also known as the manipulated variable.
- **Dependent variable:** the variable scientists observe or measure to see if it is affected by a change in the independent variable. This is also known as the responding variable.

EXAMPLE:
A student wants to test the hypothesis about water temperature and freezing rates. The independent variable is the initial water temperature, because the student will vary the starting temperatures of the water samples. The dependent variable is time, because the student will observe how the amount of time it takes for ice cubes to form changes based on the starting temperature of the water.

EXAMPLE:
A student wants to explore how changing the temperature of a gas affects 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 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). This graph shows the relationship between the temperature and volume of a gas at a constant pressure.

RELATIONSHIP OF THE TEMPERATURE AND VOLUME OF A GAS AT CONSTANT PRESSURE



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 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 compares the results from the unpainted 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 in the experimental groups. 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? The type of box would not be controlled and as a result, any differences in temperature observed could be a result of the paint but could also be a result of the box material. The student would not be able to make any reliable conclusions about which factor affected the temperature.

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 have been accepted as true by the global scientific community. They are well supported by observations, experimentation, and data. They are not facts and may change if new information becomes available, but are treated as fact until contradicting evidence is found.
- 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.

NOTES

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

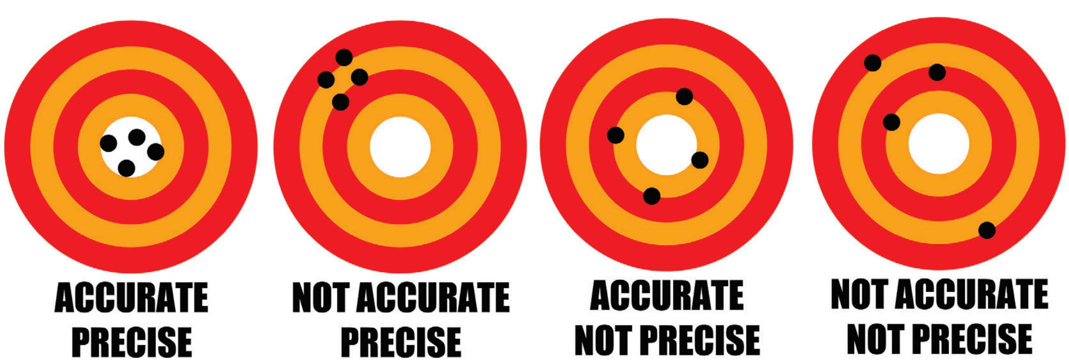
Scientists can use accuracy and precision to describe the quality of their measurements.

- 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. They measure the ball multiple times, getting the same result each time (demonstrating their equipment is precise). The NIST scientists write a report stating they think 146 grams is an accurate value. The NIST team uses reliable equipment. 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. While in Arizona, a professor at a university is given permission to measure the ball's mass. She measures its mass three times. She records the following — 141.02 grams, 141.04 grams, and 141.01 grams. All her measurements were within a 0.03 g range 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 (141 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 scale (see the **Laboratory Equipment** section - page 104).
- 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

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 their 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: 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 weigh twice as much, 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 x g, where m is mass and g is acceleration due to gravity. The value of g on Earth when determining weight in Newtons (the SI unit of force) is a constant value of 9.8 m/s^2.

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.

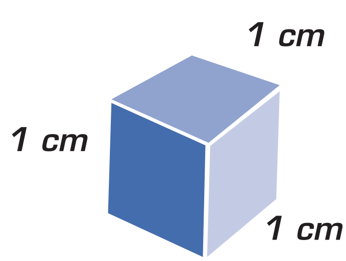
- Scientists measure volume in units of liters (L) or cubic centimeters (cm^3 or cc). One cubic centimeter is equal to one milliliter (mL).
- Volume can be measured in different ways (see the **Laboratory Equipment** section - page 104).
  - To find the volume of a liquid, you can simply pour the liquid 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.

$$\text{Volume (V)} = \text{length (l)} \times \text{width (w)} \times \text{height (h)}$$

$$\mathbf{V = l \times w \times h}$$

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?

$$\mathbf{V = l \times w \times h}$$

$$\mathbf{V = 2\ cm \times 1\ cm \times 4\ cm}$$

$$\mathbf{V = 8\ cm^3}$$

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:
$cm \times cm \times cm = cm^3$

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.
  - Normal room temperature is considered to be about 25 °C. That temperature in Kelvin is about 298 K. The answer is derived using the calculation: 25 °C + 273.15 = 298.15 K = 298 K adjusting for significant figures.
- Fahrenheit is the temperature scale commonly used in the United States. Degrees Fahrenheit can be calculated from 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.

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

- To calculate density, you must find the mass and volume of the substance. Scientists usually use kilograms per cubic meter (kg/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/cm³ 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/cm³ 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/cm³.

Air has an even lower density. The density of air at 20 °C is only 0.0013 g/cm³ at a pressure of 1 atmosphere (atm).

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 - page 104). 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 11. If the solid has an irregular shape, you will need to use a displacement method (see the **Laboratory Equipment** section - page 104). Write down your measurement.
  3. Plug your measurements of mass and volume into the density equation on page 12 to calculate the 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). The US customary unit for pressure is pounds per square inch (psi).

Quick Fact
Area is a measure of the size of a surface, 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
Atmospheric or air pressure is exerted on a surface by the weight of the air above that surface.

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.

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!

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/cm^3), 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.

NOTES

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:

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)

Quick Fact

The prefix "deca–" may also be written as "deka–." The SI spelling is deca–, but the U.S. National Institute of Standards and Technology (NIST) uses deka–. While spellings of the prefixes may be different in different countries, the symbols stay the same. Therefore, a decaliter or dekaliter is always daL.

Prefixes can be added to base units. Prefixes make the value of the unit larger or smaller. For example, one kilometer is 1,000 meters. One millimeter is 0.001 meters.

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

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

EXAMPLE:

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

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

Other SI units have been developed using 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 × 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 easily 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. "Start by converting the mass of aspirin in the second bottle of tablets to mg as follows:

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

Thus each tablet in the second bottle contains 10 mg of aspirin. 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 units. Move left to go from smaller to larger units. 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

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 more easily 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 with the first number being ≥ 1 and <10 and the second number being a multiple of the base 10.

   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

Thus the speed of light in a vacuum is 3 x 10^8 m/s in scientific notation. 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, multiplied by 10 with the appropriate exponent.

Quick Fact

Halley's Comet is visible from the earth every 75–76 years. Scientists estimate 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 easier to write the mass in scientific notation. It's much easier to read that way too!

QUICK STEPS FOR LARGE AND SMALL NUMBERS

Scientific notation can be as easy as counting. First, move the decimal in the appropriate direction to give a number ≥1 and <10. Move the decimal to the left for large numbers and to the right for small numbers. Then, count the number of places the decimal moved to figure out the correct exponent.

QUICK STEPS EXAMPLE FOR LARGE NUMBERS

Using the number of 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 in scientific notation as 5.28 × 10^3 ft.

NOTES

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 with the numerator being ≥ 1 and <10 and the deniminator being a multiple of the base 10.

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

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.

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

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), they may have an illness.

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

QUICK STEPS EXAMPLE FOR SMALL 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 in scientific notation 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, elements and compounds.
- 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 the law of conservation of energy.
- Identify and describe types of energy.
- 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 only one type of particle, which can be an element or a compound.

- Pure substances have the same composition and chemical structure throughout.
  - Every sample of a certain element generally has the same intrinsic properties as every other sample of that element, with some exceptions. For example, on a nanoscale, gold may appear purple, black, or red.
  - 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 compounds that are pure substances.

2. MIXTURE: two or more pure substances that are combined physically but not chemically.

- A mixture can be classified as **homogeneous** or **heterogeneous**.
- The different components that make up a mixture have different properties. A tossed salad is a mixture because it is made of different components—lettuce, carrots, cucumbers, tomatoes, croutons and dressing. A tossed salad is a heterogeneous mixture because it is not uniform throughout. 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 component of a mixture stays the same. Therefore, scientists can separate mixtures into their original components (see the subsection on **Physical and Chemical Separations** - page 39).
- The different components of a mixture are arranged randomly.

Quick Fact
Water that comes out of a kitchen sink is not a pure substance. Tap water usually contains minerals or other substances, so tap water is actually a mixture. Only distilled water contains only water molecules and is considered a pure substance.

EXAMPLE:

Salt and water can be combined to form a salt water mixture. The properties of this mixture may be different than the properties of each component. For example, pure water looks clear, but salt water may look cloudy. The components in salt water do not react chemically with one another and can be recovered from the mixture. The mixture still contains water (H_2O) and salt (NaCl). You can heat the salt water to convert the H_2O from a liquid to a gas (see the subsection on Physical Changes - page 32), the water in the salt-water mixture eventually vaporizes completely leaving solid salt behind. The salt also elevates the boiling point of the salt water mixture compared to the boiling point of pure water at the same atmospheric pressure.

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 - page 41). 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** - page 59).

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** - page 76)
- Has 10 stable isotopes—the largest number of stable isotopes of any element (see the subsection on **Isotopes** - page 44)
- 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 combined 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 is 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 - page 41).

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*.
- In liquid or gas form, homogeneous mixtures are usually called solutions).
  - **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 containing 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 in a particular solvent.
  - 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.
  - 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:

Raisin bran cereal is an example of a heterogeneous mixture. Raisins are more dense than bran flakes and will tend to settle to the bottom.

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.

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

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.

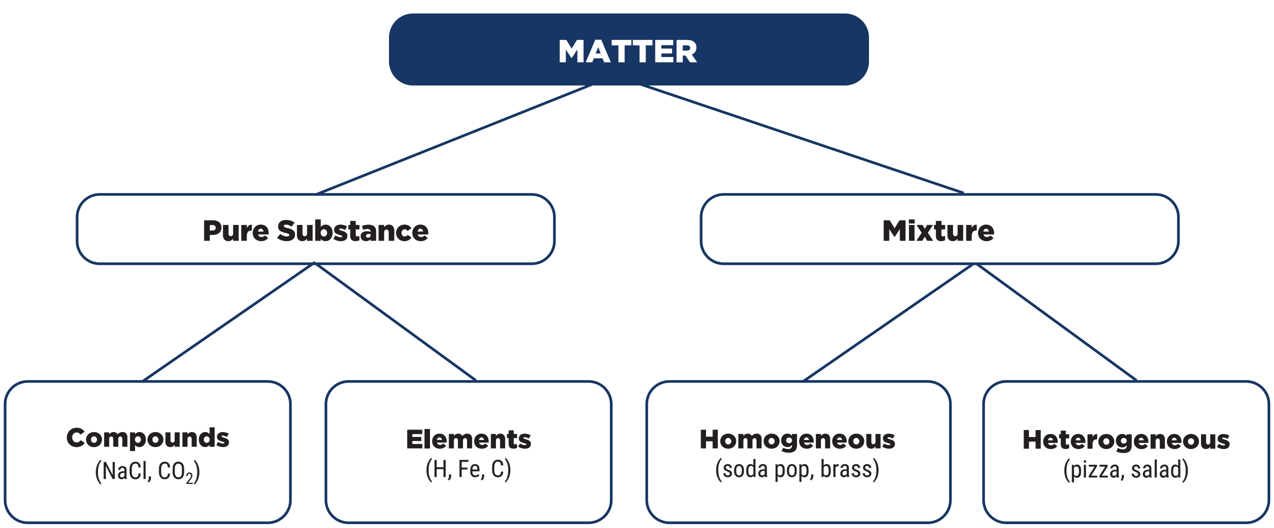
- **Gels:** consist of liquids spread throughout a solid, such as jelly, butter, and cheese.
- **Foams:** consist of gases finely spread throughout liquids or solids.
  - Whipped cream and soda pop foam are liquid foams.
  - Marshmallows and Styrofoam™ are solid foams.
- **Aerosols:** colloidal suspensions 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 components 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 because it has a lower density. 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 components mixed. However,the oil molecules are not attracted to the vinegar molecules and therefore 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 forming a layer on top of the vinegar. When small droplets recombine to form bigger ones, the process is called **coalescence**.

Quick Fact

Sometimes, it is hard to tell 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?

The following flow chart displays a summary of the different types of matter:



PROPERTIES OF MATTER

Scientists characterize 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** - page 36). 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. Oxygen is required for the chemical reaction of burning to occur. Air can provide oxygen, as can chemical oxidizers or tanks containing compressed oxygen gas.
    - 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.

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
Toxicity is dependent on the amount of a substance. Vitamins are generally important for keeping us healthy. However, they can be toxic in extremely large quantities.

Quick Fact
Some substances are EXTREMELY flammable. White or yellow phosphorous can spontaneously ignite in air without any energy change or spark!

EXAMPLE:

An iron object will rust when left outside for a long time because it reacts with the oxygen in the air. The surface forms a reddish brown coating through this chemical change. The chemical equation for this reaction is:

$$4Fe(s) + 3O_2(g) \rightarrow 2Fe_2O_3(s)$$

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** - page 32).

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/cm^3 at 20 °C. Liquid gold has a density of approximately 17.3 g/cm^3 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/cm^3.

- **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.

- **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.

Quick Fact

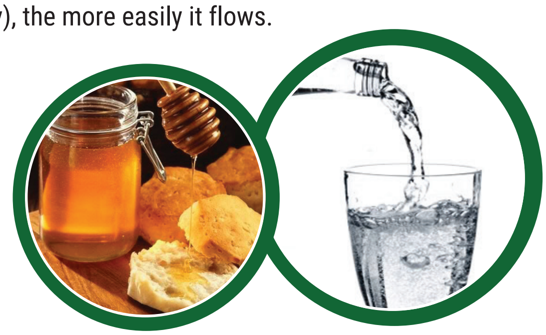
Silicon dioxide can have a crystalline structure, such as in quartz. However, when it is cooled quickly, it does not completely crystalize. Instead, it forms glass or glassy silica. Studies have shown that the SiO_2 in glass has some type of structure but not a specific, repeating one. Therefore, glass is still considered an amorphous solid.

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.

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** - page 75).



- **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.
  - 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 attracted to each other.

Quick Fact

A sewing needle is denser than water. However, when the needle is placed carefully on its side on a water surface, it will remain on the water’s surface because of surface tension. Try this yourself. Also see if you can make a paper clip float on water.

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.

- 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 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 31).

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

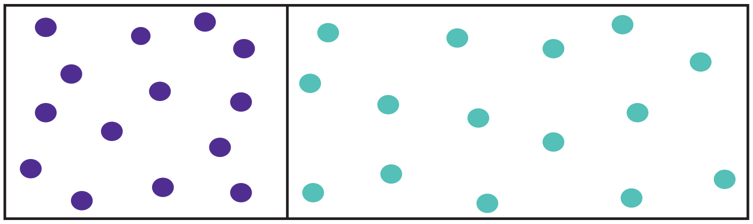
Osmosis is the diffusion of water across a semi-permeable membrane (a membrane that allows some ions or molecules to pass through, but not others).

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

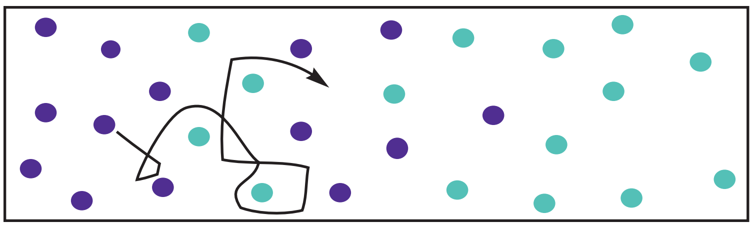
EXAMPLE:

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.

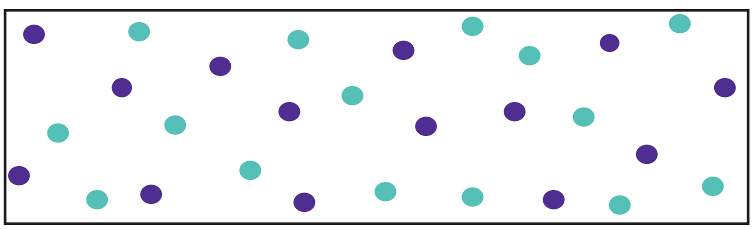
The process of diffusion is illustrated below:



The particles of two miscible fluids are separated by a barrier. Miscible fluids can be combined in any ratio to form a homogeneous solution.



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 diffuse more quickly at higher temperatures because, at higher temperatures, particles have more kinetic energy. 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 image above the particles diffuse quickly 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 - page 41).

- Plasma is the most abundant phase of matter in the universe. In this phase, electrons have been stripped from the atoms and float around freely within the plasma.
- Because the positive and negative particles 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 such as our sun produce plasmas.
- Plasma usually takes the form of neutral, gas-like clouds.
- Until about 2007, plasma displays were commonly used in large televisions. 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 is an example of a physical change. The paper is in smaller pieces, but the chemical makeup of the paper has not changed.

CHANGES OF STATE—TEMPERATURE

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

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

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

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?

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 ice.

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

- At one atmosphere (1 atm) of pressure, the melting point of ice is 0 °C or 32 °F. The melting point of silver is approximately 961 °C.
  - The term "**atmosphere**" means the air pressure at sea level. It is used as a unit of measurement for pressure.

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

- **Freezing point:** the temperature at which a liquid begins to form a solid. The substance will remain at that temperature until freezing is complete.
- At 1 atm of pressure, the freezing point of water is 0 °C. As you can see, the melting point and the freezing point of a substance are generally the same.

EXAMPLE:

A bottle of juice 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.

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.

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 (evaporate!) and escape into the air. As a result, the puddle gets smaller as time passes.

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

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

Quick Fact

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 of water 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.

DEPOSITION: a change of state directly from a gas to a solid.

EXAMPLE:

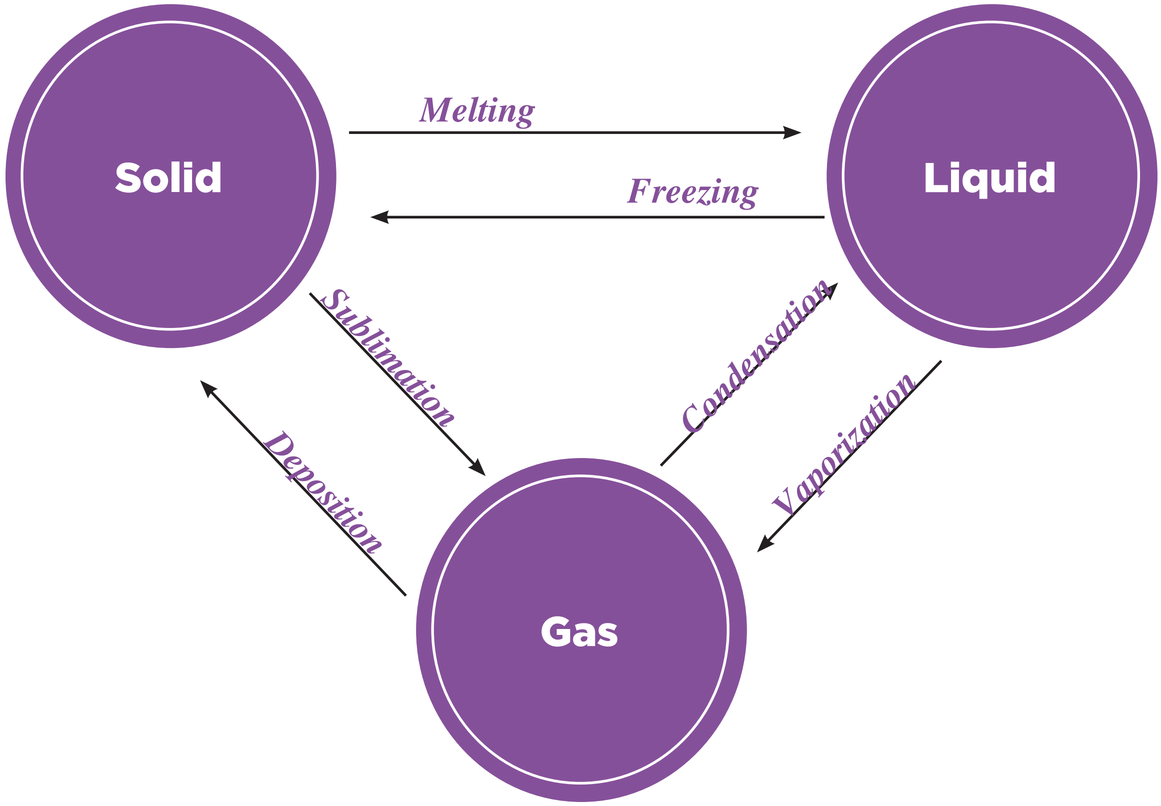
When frost forms on car windows at low temperatures, deposition has occurred. As water vapor in the air comes in contact with the freezing cold window, it turns directly to ice crystals.

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.

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



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.

Quick Fact

Volatility is a measure of how quickly a substance vaporizes at a certain temperature. It can refer to BOTH solids and liquids (sublimation and vaporization). For example, dry ice (solid CO_2) is highly volatile. It sublimes into a gas at room temperature. Likewise, gasoline has a much higher volatility than water. It will vaporize more quickly than water.

CHEMICAL CHANGES

Chemical change: a change that takes place when atoms of a substance are rearranged. 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.

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.
- Energy is present in light, sound, electricity, chemical bonds, and much more.
- Matter changes whenever energy is added or taken away. Although the energy is added or taken away, the overall amount of energy remains the same. It simply changes form.

EXAMPLE:

If you put a ball on a shelf it contains potential energy, 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.

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.

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.

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.

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: $E = mc^2$ where c is the speed of light.

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, the gravity affecting it, and it's height, you can determine its gravitational potential energy. To do so, use the equation below:

$$PE = (\text{mass}) \times (\text{gravity affecting it}) \times (\text{height}) \quad \text{or} \quad PE = mgh$$

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, like 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 in 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. 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 relates to the internal energy of the substance related to temperature.

TYPES OF ENERGY

Energy is defined as the capacity to do work or produce heat. All forms of energy are classified as either potential energy (stored energy or the potential for movement) or kinetic energy (the energy of motion). The most commonly referenced forms of energy include:

- **Chemical energy** is associated with the energy stored in the bonds between atoms in molecules
- **Electrical energy** is associated with the energy delivered by tiny charged particles called electrons, typically moving through conductive metals
- **Mechanical energy** is associated with the movement or position of objects. It includes both kinetic energy and gravitational potential energy of an object.
- **Nuclear energy** is associated with the energy stored in the nucleus of an atom and holds a nucleus together.
- **Radiant energy** is associated with the electromagnetic energy that travels in waves. Radiant energy includes visible, ultraviolet and infrared light, microwaves, x-rays, gamma rays, and radio waves.
- **Thermal energy** is associated with the random motion of particles and amounts to the total internal energy of a substance. This energy is most often measured as heat or temperature.

Energy can be converted from one form to another.

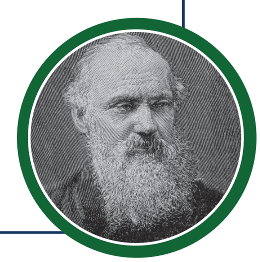
- **Law of conservation of energy** (first law of thermodynamics): while energy can change from one form to another, it can be neither created nor destroyed.

EXAMPLE:

Coal is a good source of chemical potential energy, which can be released by burning the coal. Heat from burning coal can be used to boil water, which creates steam. The energy of steam can then be used to turn a rotary engine and produce mechanical energy. The engine may give power to a generator which produces electricity (electrical energy). The electricity may be turned into light (radiant energy) in a lamp or thermal energy in an electric toaster.

HISTORY: **WILLIAM THOMSON** (1824-1907)

William Thomson (Lord Kelvin) was a Scottish physicist and mathematician known for his work on energy. He proposed that heat was based on the energy of the motion of molecules. Thomson first defined the absolute temperature scale in 1847. It was later named after him. In 1851, he published ideas leading to the second law of thermodynamics which states that when energy changes from one form to another form, or matter moves freely, the entropy (disorder) in a closed system increases.



Thomson also contributed to the first successful trans-Atlantic telegraph cables. He served as a scientific advisor during the project. In 1866, he was knighted by Queen Victoria for this work. In 1892, he received the title of First Baron Kelvin of Largs. He is now commonly referred to as Lord Kelvin.

HEAT

Heat is the transfer or flow of energy from one substance to another because of a difference in temperature. Heat will flow from a material at a higher temperature to one that is at a lower temperature.

Heat is commonly transferred (moved from one substance to another) in one of three ways:

- **Conduction:** the transfer of energy by collisions between nearby atoms.
  - Conduction is the dominant form of heat transfer in solid matter.
  - Conduction causes the metal handle of a pot on a stove to become warm. Heat moves through the metal atoms that make up the pot and excites the atoms in the handle. (Many pot handles have some type of insulating cover so they don't get too hot.)
- **Convection:** the transfer of energy by the bulk molecular motion within a liquid or gas.
  - Convection occurs because of temperature differences within a fluid or between a fluid and its container.
  - When water in a pot on the stove is heated to boiling, convection assists in circulating the heat from the bottom of the pot toward the top for faster heating.
- **Radiation:** the transfer of heat (as electromagnetic waves) through an empty space or clear material without heating the space or material.
  - The most commonly encountered form of radiation is solar radiation. In solar radiation, the rays from the sun heat up the earth (see the section on Types of Electromagnetic Radiation).

HISTORY: **KARL SCHEELE** (1742-1786)

Karl Scheele was a Swedish chemist who published a book called Chemical Treatise on Air and Fire. In this book, he distinguished heat transfer by thermal radiation from heat transfer by convection or conduction.

He discovered many chemical substances, such as barium, chlorine, manganese, molybdenum, and tungsten. Most notably, he discovered oxygen independently of and earlier than Joseph Priestley and Antoine Lavoisier. However, he published his findings after they published theirs.

Scheele is also credited with recognizing the effect of light on silver compounds, which laid the groundwork for photography.

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 components. To do this, they use separation processes.

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

- A separation process uses the different properties of the mixture's parts to get the components 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 in this example is size.

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

PHYSICAL SEPARATIONS

Physical separations use physical properties to separate the components of a mixture. This is done without changing the chemical properties of the components. There are many physical separation processes.

Filtration is a way of separating a mixture based on differences in size between the particles that make up different components 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

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.

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 components 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.
- Precipitation can also occur when a substance which is soluble in one liquid (e.g. water) passes into another liquid in which it is insoluble (e.g. alcohol). For example DNA dissolved in an aqueous solution will precipitate out when cold isopropyl alcohol is layered on top of the aqueous solution.

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.

EXAMPLE:

One example of a chemical separation through precipitation involves wastewater treatment. As lead (Pb^{2+}) is hazardous to human health, the lead must be removed from wastewater before the wastewater can be released. Chemists can accomplish this by adding sulfides (S^{2-}) or sulfates (SO_4^{2-}) to the wastewater. These substances will combine with the lead to make new solid compounds.

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

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

Once the solid compound is formed, the lead, which is a component of the solid compound, can be removed from the water by filtration. Chemical separations can be quite helpful.

SECTION IV:
ATOMIC STRUCTURE

OBJECTIVES

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

ATOMS

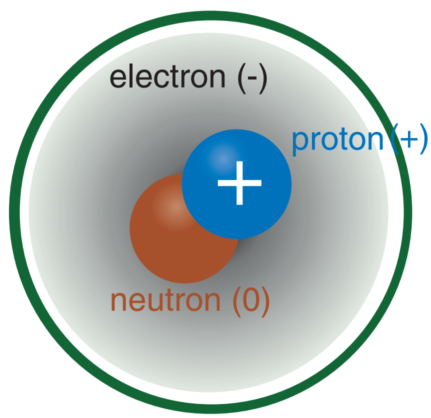
All matter is made up of atoms of elements. Elements are known as the building blocks of matter and cannot be broken down chemically into simpler substances. The elemental form of any substance is made up of only one type of atom.

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** - page 63).
  - 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 and their accepted abbreviations include these charges:



- **A proton** has a positive (+) charge. The common abbreviation for protons is p^+.
- **A neutron** does not have electric charge (0). The common abbreviation for neutrons is n^0.
- **An electron** has a negative (-) charge. The common abbreviation for electrons is e^-.

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

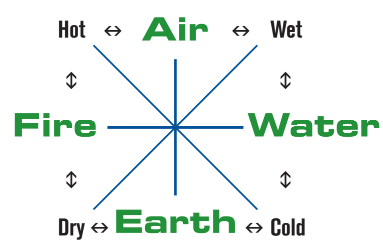
HISTORY: **ELEMENTS AND ATOMS**

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 - page 98).

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** - page 63).

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

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.

ELEMENTS AND CHEMICAL SYMBOLS

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:

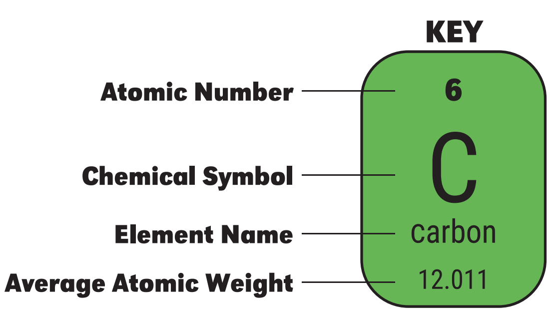
Hydrogen has the lowest atomic number. Its atomic number is one, which means it only has one proton in its nucleus.

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

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 new elements that have not yet been officially named). The first letter of a chemical symbol is always capitalized. If a chemical symbol has a second letter, it is always 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 using carbon (C) as an example.

Quick Fact

Scientists can 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.

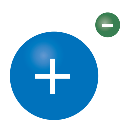


IONS

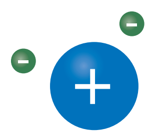
The total number of protons in an atom of an element never changes, but atoms can gain or lose electrons.

- 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 a neutral charge. Atoms with neither a positive nor a negative charge are *electrically neutral*.
- Ion: an atom or molecule that has lost or gained one or more of its outer valence 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. 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.

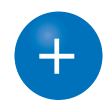
The image below shows three forms of hydrogen: the electrically neutral atom and two ions.*



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 41, has been removed for easier visualization.

ISOTOPES

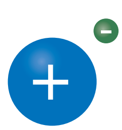
The number of protons of an element is the same for all atoms of that element, but the number of neutrons in those atoms can vary.

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

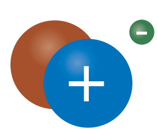
- Isotopes of an element have the same number of protons (atomic number) but a different number of neutrons in the nucleus. The mass number for each isotope of an element is different.

EXAMPLE:

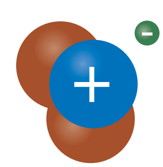
The most common isotope of hydrogen has no neutrons and is also called protium. A hydrogen isotope with one neutron is called deuterium. A hydrogen isotope with two neutrons is called tritium. The image below illustrates these isotopes of hydrogen:*



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 41, has been removed for easier visualization.

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.

H

HYDROGEN

Atomic #1

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 was used in the hydrogen bomb.

Hydrogen is also a fuel for the stars such as our sun because it is part of a nuclear process called fusion. This process releases much, much more energy than combustion, which allows stars to shine for billions of years.

Quick Fact

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

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.

The French chemist 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 (average 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.

SECTION V:
THE PERIODIC TABLE & FORCES OF ATTRACTIONS

OBJECTIVES

- Locate elements on the periodic table.
- Distinguish between the different elemental groups on the periodic table.
- Describe the periodic trends for electronegativity, ionization energy, and atomic radii.
- Utilize the periodic table to describe properties of elements and electron configuration.

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 are called **chemical symbols** and are still used today.

The first letter of a chemical symbol is always capitalized. If a chemical symbol has a second letter, it is always written in lowercase. For example, the chemical symbol for hydrogen is H. The chemical symbol for helium is He (see the subsection on **Elements and Chemical Symbols** - page 43).

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).*

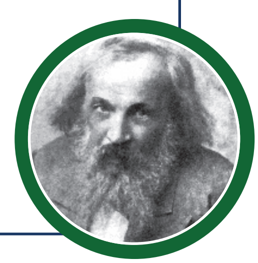
HISTORY: **THE PERIODIC TABLE OF ELEMENTS**

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.



Dmitri Mendeleev

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

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** - page 63).
- 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.

Quick Fact

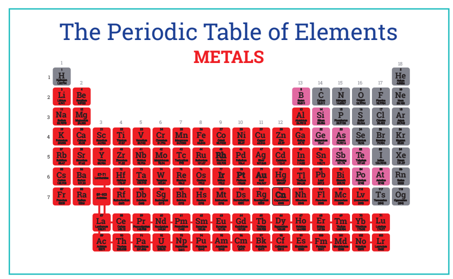
Some chemical symbols are based on the Latin name of the element. For example, the Latin name for gold is "aurum." The Latin name for lead is "plumbum."

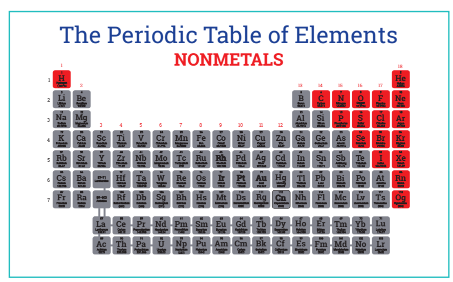
Periods: the horizontal rows on the periodic table. There are 7 periods on the periodic table.

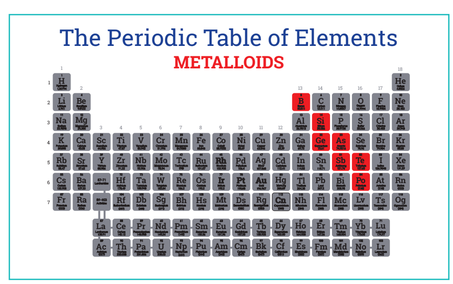
- Members of the same period do not have similar properties. Moving across the periodic table, from left to right, the properties of the elements change greatly.
- Members of the same period have the same number of electron energy levels, but they differ in how they are filled. As explained on page 60, 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** - page 76. 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.





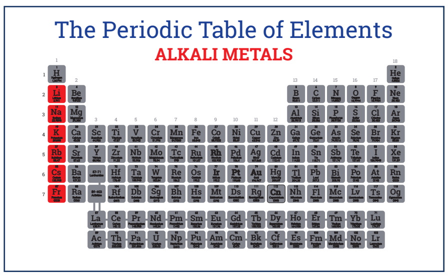


ELEMENTAL GROUPS

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
Only hydrogen, nitrogen, oxygen, fluorine, chlorine, and the noble gases are gases at room temperature as elemental substances.

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

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.

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 Acids, Bases and pH – page 94)

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 - page 98).

Quick Fact

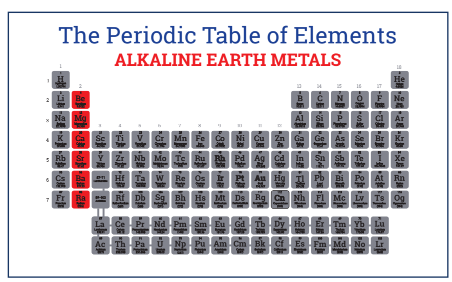
Potassium salts are electrolytes, substances that conduct electricity in the human body. Electrolytes easily separate into ions in a solution, which enables them to conduct electricity. Other electrolyte ions in the body include sodium, chloride, calcium, and magnesium.

ELEMENTAL GROUPS

GROUP 2 – ALKALINE EARTH METALS

Alkaline earth metals, including beryllium, calcium 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



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:

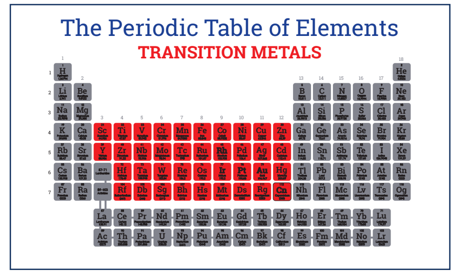
- Is the 5th most abundant element in the earth's crust
- Is not found naturally in its elemental form
- Is an essential component of leaves, bones, teeth, and shells

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.

ELEMENTAL GROUPS

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

Most elements can only use electrons from their outermost orbital to bond with other elements (see the subsection on **Electron Configuration** - page 63 and the subsection on **Periodic Trends** - page 59). 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.

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.

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 and Bonding** section - page 66).

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

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.

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. 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.

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 zinc dihydroxide-carbonate ($Zn_2(OH)_2CO_3$) 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-ray screens and had been used in cathode ray tubes in early TV's.

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.

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
  - 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.

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:

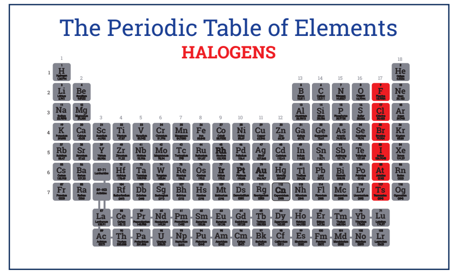
- Is the only metal element that is liquid at room temperature, which is about 75 °F
- Has very high surface tension
- Is a very good conductor of electricity but not of heat
- Is found in the red mineral mercury (II) sulfide (HgS), commonly called cinnabar

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.

ELEMENTAL GROUPS

GROUP 17 – HALOGENS



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

- Exist as diatomic molecules at normal room temperature—F_2, Cl_2 (except astatine)
- 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 (about 74ºF), 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 (often referred to as halides), include sodium chloride (NaCl) and calcium chloride ($CaCl_2$).

Quick Fact
Groups 13-16 have more variation in characteristics within each group because they contain combinations of metals, metalloids, and nonmetals. They are not discussed as groups often and do not have commonly used group names.

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

Quick Fact
Fluorine compounds are added to toothpaste to help prevent tooth decay

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** - page 59.)
- 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
Pure fluorine's reactivity makes it difficult to store. It attacks glass and causes most metals to burst into flames.

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.

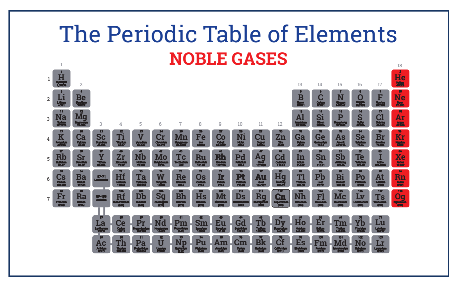
Chlorine is used to disinfect or "chlorinate" water. The amount of chlorine needed to kill harmful bacteria and other microorganisms depends on what is in the water. Adding chlorine to water can make it safer to drink. This process is used all across the world. Today, most water supplies are chlorinated. 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** - page 63).
- Do not tend to form chemical bonds and are unlikely to gain or lose electrons



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.

Quick Fact

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

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 making it safe to use in party balloons.
  - 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 (~ -460°F) at standard pressure. However, helium can be changed into its solid form by increasing the pressure and decreasing the temperature.

Ar

ARGON
Atomic #18

Argon gets its name from the Greek word "argos" meaning "inactive."

CHARACTERISTICS:

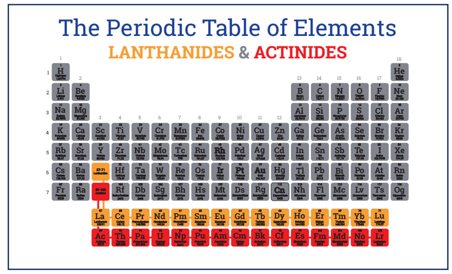
- Is colorless and odorless as a gas and a liquid
- Makes up a little less than 1% of the earth's atmosphere by volume
- Is used in incandescent light bulbs
  - Argon prevents oxygen from corroding the hot wire filament inside light bulbs.

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

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 were used in the cathode ray tubes in the early 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.

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

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.

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 of actinide properties have been difficult because of their radioactive instability.

NOTES

PERIODIC TRENDS

As mentioned previously, **valence electrons** are the electrons in the outermost energy level (or shell) of an atom (including all sublevels of the outermost energy level). They are represented as the dots that surround the chemical symbol in a Lewis symbol. For group 1-2 elements, the number of valence electrons equals their group number. For group 13-18 elements, the number of valence electrons is ten fewer than their group number (see the subsection on **Lewis Symbols** - page 66).

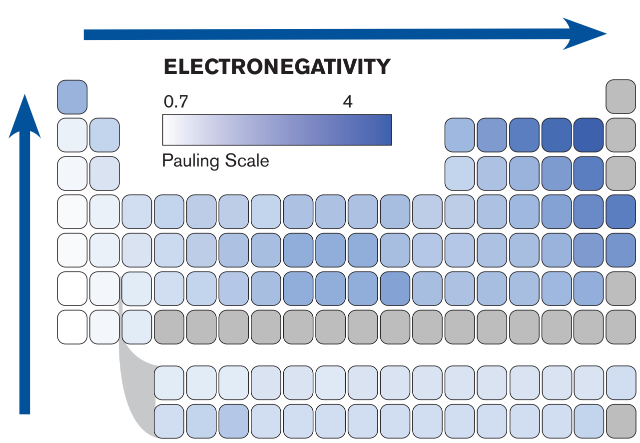
- An atom of a main group element can typically hold a maximum of eight valence electrons. The exceptions are hydrogen and helium.
- Atoms that have fewer than eight valence electrons tend to form bonds with other atoms. Atoms will give, take, or share electrons to achieve a full outermost energy level (with eight electrons), which makes them stable.
- Generally, metals lose valence electrons to become more stable and nonmetals gain electrons.

ELECTRONEGATIVITY

Electronegativity is a chemical property that describes how strongly the nucleus of an atom attracts the shared pair of electrons in a chemical bond. Electronegativity indicates how strong of a pull an atom has on electrons and how strongly it will compete for electrons during reactions. When two atoms are bonded together, the shared pair of electrons are more attracted to and more tightly bound to the more electronegative atom. The difference in electronegativity between two atoms determines what type of bond they form.

- **Within a period, electronegativity tends to *increase* from left to right**. Within the same period of the periodic table, moving one column to the right means adding one more proton and electron to the same outer electron shell (elements within the same period have the same number of electron shells). Think of proton-electron attractions as that of small magnets. The more proton-electron pairs are present in an atom, the more the outer shell is drawn towards the center of the atom. As the outer shell is drawn in and the valence electrons get closer to the attractive, positively charged nucleus, the atom holds onto its own electrons and other electrons more tightly.
- **Within a group, electronegativity tends to *decrease* from top to bottom.** Moving down one group on the periodic table means adding one more electron shell, increasing the size of the atoms. As the atoms get bigger, there is more space and there are more electrons between the nucleus and the valence electrons in the outer shell. The nucleus' ability to attract an electron decreases as the electron moves farther away from the nucleus and as more electron shells are added between that electron and the nucleus—this is called "shielding". Therefore, the nucleus of a larger atom can't attract other (or its own) electrons as well as a smaller atom.

Fluorine and chlorine have the same number of valence electrons, but fluorine is smaller, therefore fluorine is more capable of attracting electrons and adding them to its shell to complete its octet. Fluorine is more electronegative than chlorine (See the subsection on **Atomic Radii** - page 61).



*Electronegativity is measured on the Pauling scale, with 0.7 being the least and 4.0 being the most electronegative.

**The electronegativity is unknown for the elements on the table shown in gray. This includes all the noble gases besides krypton and xenon, as well as elements 103 through 118.

***The arrows indicate the general trend of electronegativity: it increases moving to the right within a period and moving up within a group.

The most strongly electronegative elements are found in the upper right of the periodic table (excluding the noble gases). Fluorine is the most electronegative element. Francium is the least electronegative, meaning its nucleus attracts electrons more weakly than any other element. Francium is the most "electropositive" element.

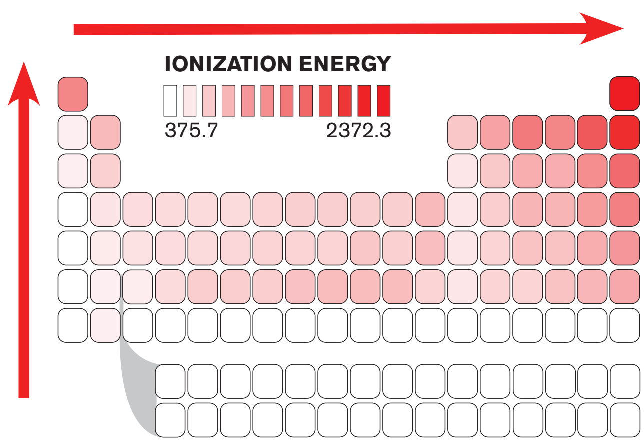
EXAMPLE:

The electronegativity (from least to greatest) for the second row of the periodic table is: Li, Be, B, C, N, O, F. Notice that neon (Ne) is not listed. Neon's outermost energy level, level 2, already has eight valence electrons (an octet). Since the outer shell is full, neon does not need to gain or lose electrons - it is already stable!

IONIZATION ENERGY

Ionization energy is the amount of energy needed to remove one of the outermost electrons from a neutral atom in the gas phase. Each negatively charged electron is attracted to the positively charged nucleus, so in order to remove an electron a certain amount of energy (the ionization energy) is needed to overcome that attraction. Think of ionization energy as an indicator of how strongly an atom holds onto its valence electrons. A higher ionization energy means the atom has a stronger hold on its valence electrons, so it takes more energy to get the electrons away from the atom and its nucleus. A lower ionization energy means that the atom can more easily lose its valence electrons, and the electrons are not as tightly bound to the nucleus.

- **Within a period, ionization energy tends to *increase* from left to right across the periodic table.** Much like electronegativity, this trend occurs because of the increasing number of protons and electrons. More protons and electrons means more proton-electron pairs attracted to one another (again, think of proton-electron attractions as that of small magnets). As proton-electron pairs are added, the electron shell is pulled closer to the nucleus. Electrons closer to the nucleus are more strongly attracted to the nucleus, so it requires more energy to overcome that attraction and remove an electron.
- **Within a group, ionization energy tends to *decrease* from top to bottom down the periodic table.** Also similar to electronegativity, this trend occurs because atoms get larger moving down a group. The valence electrons are in electron shells farther and farther from the nucleus. Less energy is needed to remove an electron that is farther from the nucleus, so ionization energy decreases as atoms get larger moving down a group.



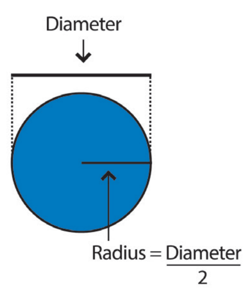
*In the table above, ionization energy is measured in kilojoules per mol (kJ/mol).
**The ionization energy is unknown for the elements on the table shown in white.
***The arrows indicate the general trend of ionization energy. It increases moving to the right within a period and moving up within a group.

Ionization energy and electronegativity trends explain why metals and nonmetals react differently to achieve stability. Metallic elements like sodium lose, rather than gain, electrons to reach an octet because they have lower ionization energies (and lower electronegativity). Moving to the right across the periodic table, atoms get closer to having a full octet, become more electronegative, and have higher ionization energy. As a result, nonmetals are more likely to gain, rather than lose, electrons and become like the noble gas in their same period, rather than losing electrons to become like the noble gas in the period above.

Since atoms want to be stable, elements like the halogens (fluorine, chlorine, etc.) that are only one electron away from a full octet will want to gain an electron, and it will take more energy to take one away. Notice that noble gases have higher ionization energies because they already have an octet and are therefore stable. (See **Octet Rule** subsection - page 69)

ATOMIC RADII

The **atomic radius** of an element's atom is a measure of atomic size. For a single atom, it can be considered as the typical distance from the nucleus to the boundary of the electron cloud. To understand this, think of an atom as a ball. The radius of the ball can be found by measuring from the center of the ball to the edge. It can also be found by dividing the diameter by two.

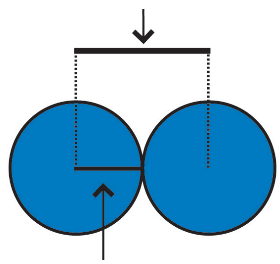


In actuality, an atom does not have a clearly defined edge because of the electron cloud. The atomic radius is determined by how close one atom is to a neighboring atom. It is half the distance between the nuclei of two atoms of one element that are bonded together. This distance is so small that it is typically measured in picometers (1 pm = 10^{-12} m).

EXAMPLE:

The atomic radius for bonded metallic atoms in an elemental sample, like sodium, is half the distance between the nuclei of the two neighboring atoms.

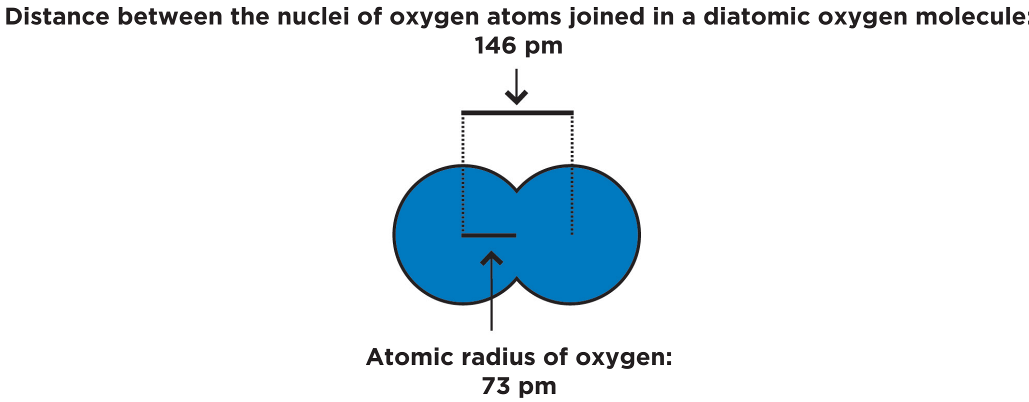
Distance between the nuclei of two neighboring sodium atoms: 372 pm



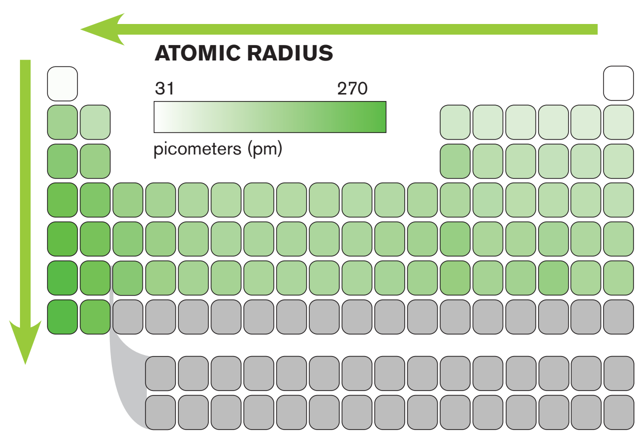
Atomic radius of sodium: 186 pm

EXAMPLE:

In a bonded nonmetal, like oxygen or another diatomic molecule, the radius is half the distance between the nuclei of the atoms in the molecule.



- **Atomic radii tend to *decrease* from left to right across the periodic table.** Similar to electronegativity and ionization energy, this trend results from the increasing positive charge in the nucleus from left to right across a period. The more positively charged nucleus attracts the electrons more strongly and pulls them closer to the nucleus.
- **Atomic radii tend to *increase* from top to bottom down the periodic table.** This trend is caused by the increasing energy levels (and thus larger orbitals). The electrons are farther from the pull of the positive nucleus, and are therefore not held as tightly or as closely.



*In the table above, the atomic radii are measured in picometers (pm).
**The atomic radius is unknown for the elements on the table shown in gray.
***The arrows indicate the general trend for atomic radii. It increases as you move to the left within a period and as you move from the top to the bottom within a group.

Knowing the atomic radii of elements can help to explain their ionization energies. If the radius of an element is small, the electrons are closer to the nucleus. This means that the protons in the nucleus are more strongly attracting and pulling in the electrons in the outer shells. The amount of energy needed to pull an electron off (the ionization energy) gets smaller as the distance between the valence electrons and nucleus gets larger, and as more electrons are added between the valence electrons and nucleus. When there are more electrons shells, the attraction between the nucleus and the outermost electrons is weaker, so pulling off an electron will be easier and require less energy.

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 visualize 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 region outside of the nucleus where an electron is most 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. For example, a level 3 electron is at a higher energy level than a level 2 electron.

Quick Fact

"Shells" is a simplified way to represent principal quantum number because orbits in shells are easier to visualize than orbital probability clouds. If electrons have the same principal quantum number (the same energy level), those electrons are in the same shell. However, remember that electrons are not actually in shells. They are in orbitals.

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

EXAMPLE:

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

An electron with more energy can occupy more of the different types of orbitals. You can think of electrons like people. The more energy a person has the more places they are 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.

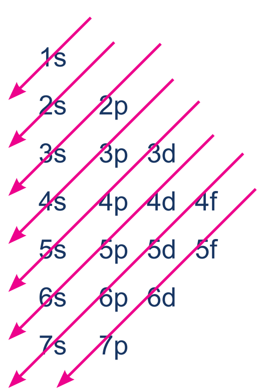
The table below breaks down the amount of electrons that different types of sublevels or subshells can "hold":

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.



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.

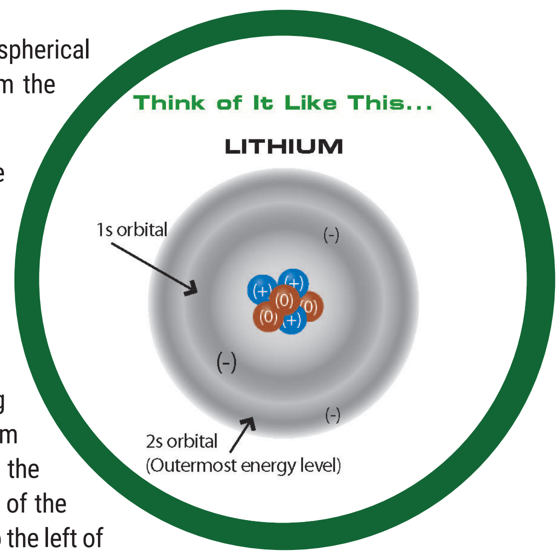
$$1s^2$$

- 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.

Quick Fact

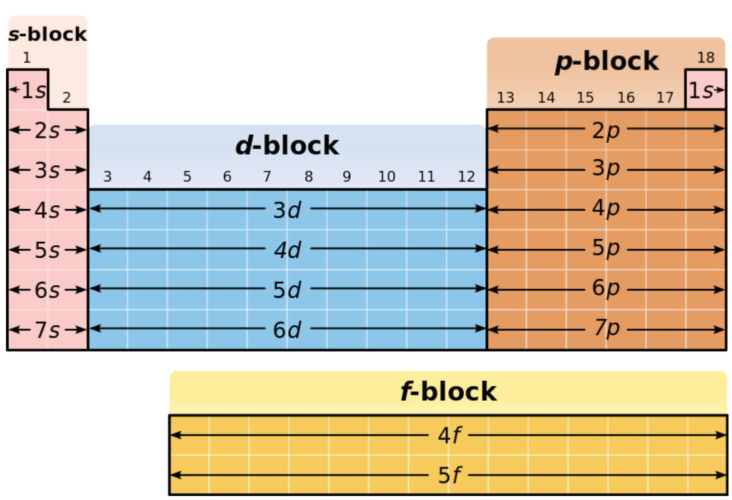
Notice that electrons fill in the 4s orbital before the 3d orbital. The 3d state is at a higher energy level than the 4s even though the 3d state has a lower principal quantum number. There is no simple explanation here, but it has to do with how an electron interacts with all the other electrons already 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, they may stay at the base camp if there are already too many people at the top.

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 orbital filling diagram on page 64). 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 valence electron configurations but with increasing number of energy levels as you move down the table.



SECTION VI:
CHEMICAL FORMULAS AND BONDING

OBJECTIVES

- Identify the Lewis symbols for different elements.
- Identify and write chemical formulas using chemical symbols.
- Recognize common chemical compounds and their formulas.
- Use the guidelines of chemical nomenclature to name chemical compounds.
- Identify the three primary types of bonds.
- Use Lewis structures to illustrate bonding.

LEWIS SYMBOLS

Scientists have many different ways to represent an atom of an element. One way is to write the element's ground-state electron configuration (see the subsection on **Electron Configuration** - page 63). Another way is to use **Lewis symbols**. Lewis symbols (also known as electron dot structures) contain the element's chemical symbol and dots that represent the high-energy outermost electrons, called valence electrons. Remember, each element has a unique chemical symbol of one or two letters, as shown on the periodic table.

VALENCE ELECTRONS

Valence electrons are the electrons in the highest energy level, located in the electron shell the farthest from the nucleus of an atom (see **Periodic Trends** - page 59). Atoms often react using their valence electrons, so looking at a Lewis symbol and knowing how many valence electrons an element has can help determine how it will react with other elements. The electrons not in the highest energy level are known as **core electrons**, and are not usually involved in chemical reactions.

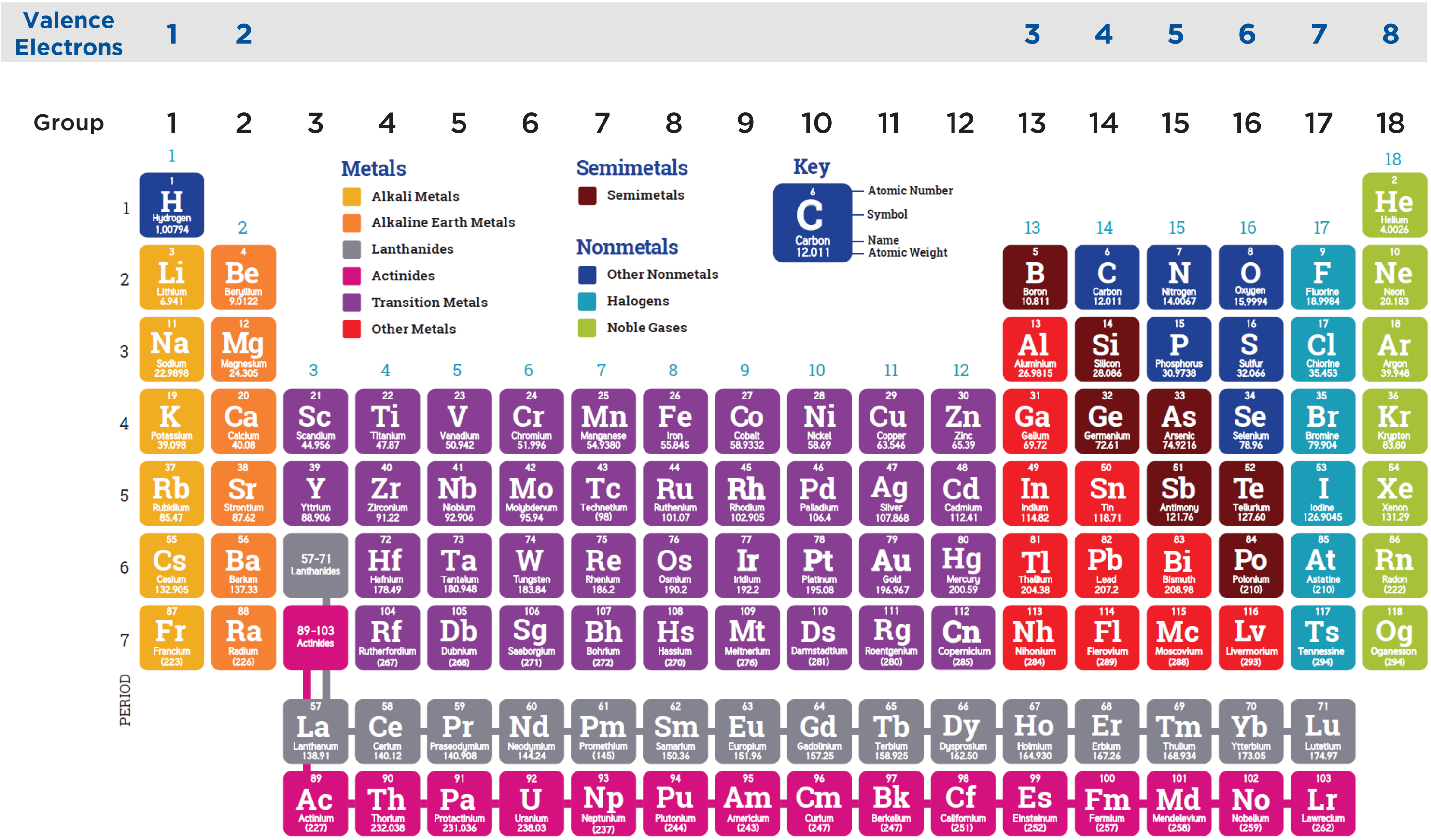
Most main group elements (elements in groups 1-2 and groups 13-18) can have up to eight valence electrons. Transition metals (groups 3-12) do not follow this rule.

Groups 1-2 and 13-18 (the main group elements) all follow the same pattern of valence electrons. Moving from left to right across the periodic table, one electron is added with each group. The number of valence electrons increases by one with each group from left to right, not including the transition metals (groups 3-12, colored purple), as shown on the following page.

Quick Fact

The ground-state electron configuration of an atom shows the lowest energy state of the atom. In the presence of light energy, electrons can sometimes absorb energy to jump to a higher energy level, changing the electron configuration. This is called an excited state.

VALENCE ELECTRONS BY PERIODIC GROUP



- Groups 1-2: the number of valence electrons equals the element's group number on the periodic table. For example, calcium is in group 2 and has two valence electrons.
- Groups 13-18: the number of valence electrons is ten fewer than the element's group number. For example, oxygen is in group 16 and has six (= 16 - 10) valence electrons.
- Groups 3–12: the process is not so simple for the transition metals. Transition metal atoms can use electrons from their inner shells as valence electrons, so the number of valence electrons varies.
- Group 18: the noble gases in the last group on the periodic table each have eight valence electrons. Since eight is the maximum number of electrons that can fit into each of these atom's outermost energy level, each of the noble gases has a **full octet**. Atoms are most stable when they have eight valence electrons, making the noble gases generally unreactive.

The noble gas helium is an exception with only two valence electrons. Its outermost energy level is only a 1s orbital, which is full with two electrons, making helium stable.

DRAWING LEWIS SYMBOLS

The Lewis symbol of one atom of an element depends on the element's chemical symbol and the number of valence electrons that atom has.

To draw the Lewis symbol of one atom of an element, use the following steps:

1. Write the chemical symbol of the element. The symbol represents the nucleus and all of the electrons not in the valence shell (the core electrons).
2. Determine the number of valence electrons based on the element's periodic table group.
3. For each of the first four valence electrons, draw a single dot on each side of the chemical symbol.
4. After there is one electron dot on each side, each additional electron can be paired with another electron dot until all valence electrons are shown in the structure.

EXAMPLE:

To draw the Lewis symbol of one atom of nitrogen, begin with the chemical symbol "N." Nitrogen is in group 15. To determine the number of valence electrons, we subtract ten from fifteen and find that nitrogen has 5 valence electrons.

Add the first four valence electrons with one dot on each side of the chemical symbol:

Finally, add one more electron to reach a total of five valence electrons. This is the Lewis symbol for one atom of nitrogen:

Atoms of other elements can be drawn using these same steps. The table below shows the Lewis symbols for all atoms in Period 2 of the Periodic Table plus Chlorine in Period 3.

Atom of Element	Lewis Symbol
Lithium	Li•
Beryllium	•Be•
Boron	
Carbon	
Nitrogen	
Oxygen	
Flourine	
Neon	
Chlorine	

Lewis symbols help illustrate why elements of the same group tend to react similarly. Look at the Lewis symbols for fluorine and chlorine above. The Lewis symbols for elements in the same group have the same number of valence electrons. All of the halogens (group 17) need just one more electron to have a full octet and be stable, so they will all participate in reactions where they gain one electron (see the subsection on **Types of Chemical Bonds** - page 76).

THE OCTET RULE

The number of valence electrons indicates how many bonds an element is likely to make. The number of electrons that an atom tends to gain, lose, or share (and therefore the number of bonds that atom will make) can be predicted by the octet rul**e**, which states that:

- Atoms of main group elements are more stable when they have eight valence electrons, so they gain, lose, or share electrons by forming chemical bonds with other atoms. Atoms form bonds in such a way that they achieve an **octet** of valence electrons (eight valence electrons).
- A metal element tends to lose electrons until it has the same electron configuration as the noble gas in the period above itself. Sodium tends to lose an electron to achieve the same electron configuration as neon.
- A nonmetal element tends to gain or share electrons until it has the same electron configuration as the noble gas in the same period as itself. Sulfur tends to gain two electrons to achieve the same configuration as argon.
- Hydrogen, lithium, and beryllium are exceptions to the octet rule because when forming chemical bonds they achieve the same electron configuration as the noble gas helium, which has only two electrons.

Think About It...

Argon's electron configuration is $1s^2 2s^2 2p^6 3s^2 3p^6$. What ion of chlorine has the most stable electron configuration? What about calcium?

WRITING CHEMICAL FORMULAS

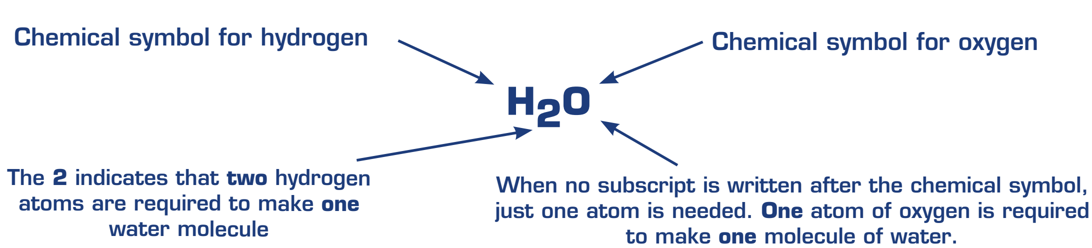
When atoms form chemical bonds to gain or lose electrons according to the octet rule, those atoms form a compound. Remember, a compound is a pure substance made up of two or more **atoms** that are chemically combined in a whole-number ratio. The **chemical formula** of a compound shows which elements it contains, as well as how many atoms of each element. Chemical formulas use **subscripts** to indicate how many atoms of each element there are in a given compound. Subscripts are the numbers located at the lower right of a chemical symbol.

Quick Fact

In a chemical formula, the less electronegative element is written first. After reading about electronegativity in the subsection on Periodic Trends (page 59), this will be an easier way to determine the order of elements in a chemical formula than oxidation number.

EXAMPLE:

Water is a compound that contains the elements hydrogen and oxygen. Two hydrogen atoms and one oxygen atom are needed to form one water molecule, so the chemical formula is H_2O.



The subscripts after hydrogen and oxygen in the previous example show how many atoms of each element are needed to make a molecule of water: 2 hydrogen atoms and 1 oxygen atom.

CHEMICAL FORMULAS OF COMMON COMPOUNDS

The following table lists some common compounds and their chemical formulas.

Common Name	Chemical Name	Chemical Formula
Alcohol (grain alcohol)	Ethanol (ethyl alcohol)	C_2H_5OH
Bleach (chlorine bleach)	Sodium hypochlorite	$NaOCl$ (aq)*
Chloroform	Trichloromethane	$CHCl_3$
Laughing gas	Nitrous oxide (dinitrogen monoxide)	N_2O
Lye	Sodium hydroxide	$NaOH$
Quicklime	Calcium oxide	CaO
Silica (sand)	Silicon dioxide	SiO_2
Rock salt (halite)**	Sodium chloride	$NaCl$
Table sugar (cane sugar)	Sucrose	$C_{12}H_{22}O_{11}$
Vinegar	Acetic acid	CH_3COOH (aq)*
Water	Water	H_2O
Wood alcohol	Methanol (methyl alcohol)	CH_3OH

* An aqueous solution is a solution in which the solvent is water. Vinegar is actually a mixture of acetic acid in water. To indicate an aqueous solution, scientists generally list (aq) after the chemical formula. For example, in the chemical equation H_2CO_3 (aq)→H_2O (l) + CO_2 (g), carbonic acid, H_2CO_3, is dissolved in water. The equation also shows that it breaks down to produce liquid water and gaseous carbon dioxide.

** Halite, commonly known as rock salt, is the mineral form of NaCl. Common table salt is also primarily made of NaCl (generally about 97%–99% NaCl), but it may also contain other chemical substances, such as magnesium carbonate. Many brands of table salt also contain additives, such as iodine salts, for health reasons.

NAMING CHEMICAL COMPOUNDS

Chemical nomenclature is the system used for naming chemical substances. There are millions of identified chemical compounds, so naming them all would be difficult without a set of systematic rules. Some compounds have been recognized for a long time and have common names (like water) but most compounds do not have common names. Instead, they have standard names based on the naming rules established by the International Union of Pure and Applied Chemistry (IUPAC). The rules for naming compounds depend on the type of compound. Similar compounds, like acids or ionic compounds, have similar names.

Quick Fact

There are exceptions for naming compounds. According to the guidelines for naming compounds, the chemical name of water should be dihydrogen monoxide. Instead, the IUPAC name for water is actually oxidane. However, water is most commonly called "water," even by scientists.

Quick Fact

Chlor*ine* changes to chlor*ide* in the compound sodium chloride. For some elements, the name is changed to end in *-ide* when the element gains electrons to become an ion.

NAMING IONS AND IONIC COMPOUNDS

An ion is an atom or molecule that has lost or gained one or more of its valence electrons. Atoms that have lost electrons and acquired a positive charge are called **cations**. Atoms that have gained electrons and acquired a negative charge are called anions. Ions formed from a single atom are called **monatomic ions**.

- Monatomic cations formed from atoms keep the same name as the element.

Symbol	IUPAC Name
K^+	Potassium ion
Na^+	Sodium ion
Al^{3+}	Aluminum ion
H^+	Hydrogen ion

- If a metal can form different cations, the positive charge is shown by placing Roman numerals in parentheses after the metal name. Many of the transition metals can take on different charges and still be stable. Take a look at the ions of iron in the table below. Both cations are stable and are likely to form.

Symbol	IUPAC Name
Fe^{2+}	Iron(II) ion
Fe^{3+}	Iron(III) ion

Scientists sometimes include Roman numerals even for metals that do not form more than one cation. For example, although Al^{3+} is the most common aluminum ion, it is also theoretically possible for aluminum to have a charge of 1+ or 2+. Scientists can write "aluminum(III) ion" to specify which ion is present.

To distinguish anions from cations, anions have different endings to their names.

- Monatomic anions are named by replacing the ending of the element name with "–ide."

Symbol	IUPAC Name
H^-	Hydride ion
Cl^-	Chloride ion
N^{3-}	Nitride ion

Ions containing more than one type of atom are **polyatomic ions.** When writing the symbol/formula of a polyatomic ion, the symbol of the cation is written first, followed by the symbol of the anion. The overall charge of a polyatomic ion is the sum of the individual oxidation numbers for each atom in that ion.

- Polyatomic *cations* formed from nonmetal atoms have names that end in "–ium."

Symbol/Formula	IUPAC Name
NH_4^+	Ammonium ion
H_3O^+	Hydronium ion

- Polyatomic *anions* may be written in different ways depending on the number of atoms and the elements that combine. For example, some are named in the same way as monatomic ions with "–ide" at the end of the name (as a suffix).

Symbol/Formula	IUPAC Name
OH^-	Hydroxide ion
CN^-	Cyanide ion

- Polyatomic *anions* that contain oxygen have names that end in "–ate" or "–ite." These anions are known as **oxyanions**. When an element can form two different oxyanions with the same charge, the suffix "–ate" is used for the oxyanion with one more oxygen than the oxyanion with the suffix "–ite." As shown below, sulfate and sulfite have the same charge, but sulf*ate* has one more oxygen atom than sulf*ite*.

Symbol/Formula	IUPAC Name
SO_4^{2-}	Sulfate ion
SO_3^{2-}	Sulfite ion

- An ion that contains hydrogen and an oxyanion is named by adding the word hydrogen or dihydrogen at the beginning of the name (as a prefix).

Symbol/Formula	IUPAC Name
HCO_3^-	Hydrogen carbonate ion
$H_2PO_4^-$	Dihydrogen phosphate ion

Ionic compounds are formed from oppositely charged ions bonded together by electrical forces (remember, opposite charges attract). When writing the name or symbol/formula of an ionic compound, the name or symbol/formula of the cation is written first, followed by the name or symbol/formula of the anion.

NAMING ACIDS

Chemical compounds that release hydrogen cations (H^+) when they are dissolved in water are **acids** (see the **Acids, Bases, and pH** section - page 94). Many acids are covalently bonded compounds composed of two parts: negatively charged ions (monatomic or polyatomic anions) combined with enough positively charged hydrogen cations (H^+) to make the compound electrically neutral. The acids ionize in water to produce one or more hydrogen cations (H^+) and an anion that may be polyatomic.

Some acid compounds have only two elements: hydrogen and one other element. These compounds are called binary acids and do not contain oxygen.

- To name *binary* acids use the following steps:

1. Start with the prefix "hydro–."
2. Add the name of the monatomic anion (the element that is not hydrogen).
3. Change the "–ide" ending of the monatomic anion name to "–ic."
4. Add the word "acid" to the end of the name.

Quick Fact
Hydrofluoric acid actually refers to HF that is dissolved in water, or HF(aq). When HF is in the gas phase, it is called hydrogen fluoride.

EXAMPLE:

For the acid HF, begin with the prefix "hydro." Then, add on the name of the monatomic anion of fluorine, which is fluoride. The result of the first two steps is "hydrofluoride." Next, change the "–ide" ending to "–ic." This gives the name "hydrofluoric." Finally, add the word "acid." The name of the compound HF is hydrofluoric acid.

Symbol/Formula	IUPAC Name
HCl	Hydrochloric acid
H_2S	Hydrosulfuric acid

Many other acids contain oxygen. These acids are called oxyacids. There are two main methods for naming acids that contain oxygen, depending on the name of the polyatomic anion involved.

- To name *oxyacids that contain a polyatomic anion with a name ending in "–ate"* use the following steps:

1. Start with the name of the polyatomic anion.
2. Change the "–ate" ending "of the polyatomic anion name to "–ic."
3. Add the word "acid."

Think About It...
Look back at the definition of an acid. Why do HF(aq) and HF(g) have different names? Is HF(g) still an acid?

EXAMPLE:

For the acid $HClO_3$, begin with the name of the anion. ClO_3^- is a chlorate ion. Next, change the "–ate" ending to "–ic." This gives the name "chloric." Finally, add the word "acid." The name of the compound $HClO_3$ is chloric acid.

Symbol/Formula	IUPAC Name
HNO_3	Nitric acid
H_2SO_4	Sulfuric acid

Notice that sulfuric acid is an exception to step 2 above because its name is not "sulfic acid." Another exception is phosphate, PO_4^{3-}. The acid H_3PO_4 is called phosphoric acid, rather than "phosphic acid."

- To name *oxyacids that contain a polyatomic anion with a name ending in "–ite"* use the following steps:
    1. Start with the name of the polyatomic anion.
    2. Change the "–ite" ending of the polyatomic anion name to "–ous."
    3. Add the word "acid."

EXAMPLE:

For the acid compound $HClO_2$, begin with the name of the anion. ClO_2^- is a chlorite ion. Next, change the "–ite" ending to "–ous." This gives the name "chlorous." Finally, add the word "acid." The name of the compound $HClO_2$ is chlorous acid.

Symbol/Formula	IUPAC Name
HNO_2	Nitrous acid
H_2SO_3	Sulfurous acid

Notice that sulfurous acid (H_2SO_3) is an exception to step 2 above because its name is not "sulfous acid." Another exception is phosphite, PO_3^{3-}. The acid H_3PO_3 is called phosphorous acid, rather than "phosphous acid."

NAMING MOLECULAR COMPOUNDS

Molecular compounds are formed by combining two or more nonmetal atoms. They are typically held together by covalent bonds (see the section on **Types of Chemical Bonds** - page 76).

- To name binary molecular compounds from the molecular formulas use the following steps:
    1. Write the name of the element that is the most electropositive (least electronegative). This is usually the element that is farther to the left in the periodic table. If both elements are in the same group, then the element with the higher atomic number is usually written first.
    2. Write the name of the second element.
    3. Change the ending of the second element to "–ide."
    4. Use the Greek prefixes below to represent the number of atoms of each element in the compound.

Prefixes	
1: mono-	6: hexa-
2: di-	7: hepta-
3: tri-	8: octa-
4: tetra-	9: nona-
5: penta-	10: deca-

EXAMPLE:

For the molecular compound CO, oxygen is found farther to the right on the periodic table, and therefore attracts electrons more strongly than carbon does. Since carbon is found farther to the left on the periodic table, it is less electronegative. Therefore, carbon is written first. Oxygen is written second, and its ending is changed to "–ide." At this point, the name is "carbon oxide." Finally, add the Greek prefix "mono–" to oxygen. The name of the compound is carbon monoxide. (Note the extra "o" is dropped).

In some cases, the prefix "mono-" is left out implying just one atom of the element; e.g. ZnO has the name zinc oxide. Likewise, the name of the molecular compound CO_2 is carbon dioxide.

Symbol/Formula	IUPAC Name
Cl_2O	Dichlorine monoxide
NF_3	Nitrogen trifluoride

Remember, these rules apply only to molecular compounds, which are made of nonmetal atoms bonded together. The rules for naming combinations of metal and nonmetal atoms (see the subsection on **Ionic Compounds** - page 71) are not the same.

INTRAMOLECULAR FORCES

Although forces are most often discussed in relationship to gravity and pressure, a force is any kind of push or pull on an object. Pressure is a type of force that requires objects to touch, so it is known as a contact force. Friction, air resistance, and tension are also examples of contact forces. There are other forces that can act on objects at a distance; these are known as non-contact forces. These forces include intermolecular and intramolecular forces. An intermolecular force is a force acting between two or more molecules. An intramolecular force is a force acting within an atom, ion, or molecule.

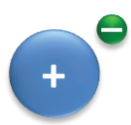
Quick Fact

Quantum mechanics explains why the electrons in an atom stay a certain distance away from the nucleus. Otherwise, protons and electrons would simply crash into one another because of Coulomb's law and the attraction of their charges.

Intramolecular forces of attraction hold together atoms and molecules. These forces are described by Coulomb's law which states that:

1. The charges in an atom or molecule attract if they are different (one positive and one negative). The attraction is greater when the charges are higher.
2. The charges in an atom push each other apart if they are the same (both positive or both negative).

For example, two electrons repel each other because they both have negative charges. An electron and a proton attract each other because one is negative and one is positive.

	The electron (-) is attracted to the proton (+) at the center of an atom.*
	The two electrons repel each other, and their like charges push them away from each other.*
	Both of the two electrons are attracted to the proton but still repel one another. They tend to be close to the proton but not close to each other.*

*In the atom images above, the electron cloud has been removed for easier visualization. The images are not to scale.

These forces also occur in ions and ionic compounds. Just like protons and electrons, cations and anions are attracted to one another. For example, an ammonium cation (NH_4^+) will be attracted to a chloride anion (Cl^-). A bromide anion (Br^-) will be attracted to a potassium cation (K^+).

Coulomb's law and other principles of chemistry, such as quantum mechanics, combine to explain the structure of atoms.

TYPES OF CHEMICAL BONDS

Quick Fact
There are seven elements that appear most commonly as diatomic molecules in their elemental state, they are hydrogen, nitrogen, oxygen, fluorine, chlorine, bromine, and iodine. The mnemonic device HOFBrINCl (pronounced "hoffbrinkle") can be used to help remember the diatomic elements.

CHEMICAL BONDS

A chemical bond is an intramolecular force of attraction that holds together atoms in a molecule or compound. Bonds are formed as a result of the attraction between the positive nucleus of one atom and the negative electrons of another atom. Chemical bonds can also be formed by the attraction between positive and negative ions. Ionic bonds, for example, are the result of attraction between oppositely charged ions.

Atoms work to achieve a stable octet arrangement of valence electrons. Atoms and molecules give, take, or share their valence electrons during chemical reactions in order to reach this stable state. When atoms or ions of different elements interact, chemical bonds can be formed, broken, or rearranged to create new compounds. Therefore, a chemical change takes place.

EXAMPLE:

Hydrogen is commonly found on the earth as diatomic hydrogen gas. Two hydrogen atoms combine to make up a molecule of hydrogen gas (H_2). Likewise, a molecule of oxygen gas (O_2) contains two bonded oxygen atoms. When a molecule of oxygen gas combines with two molecules of hydrogen gas, the hydrogen-hydrogen bonds in H_2 and the oxygen-oxygen bonds in O_2 break. Each oxygen atom then forms two new bonds, each to a different hydrogen atom, producing H_2O molecules (see the Chemical Reactions section - page 84).

$$2H_2 + O_2 \rightarrow 2H_2O$$

There are three types of chemical bonding: ionic, covalent, and metallic. Bonding involves only the valence electrons of an atom (see the subsection on **Valence Electrons** - page 66).

IONIC BONDING

Ionic bonds occur when one atom gives up electrons and another atom takes them. The atom that gains electrons becomes a negative ion (anion). The atom that loses electrons becomes a positive ion (cation). The resulting ions have opposite charges and become attracted to one another. This force of attraction holds the ions together. Compounds held together by ionic bonds are called ionic compounds.

Ionic bonds typically occur between metal atoms and nonmetal atoms because of their very different electronegativities. The less electronegative atom (the metal) readily gives up electrons, and the more electronegative atom (the nonmetal) readily accepts these electrons. The resulting metal cation and nonmetal anion are attracted to each other because of their opposite charges. The cations and anions in an ionic bond can also be polyatomic.

As a result, individual atoms or ions are not held together closely by shared electrons, as is the case with covalent bonds. There are no distinct, individual molecules, but rather a collection of ions held together by the attraction of their charges. Ionic compounds exist as three-dimensional networks of ions all connected by ionic bonds.

EXAMPLE:

When sodium (Na) and chlorine (Cl) combine to make sodium chloride (NaCl), the chlorine atoms want to take the valence electrons from the sodium atoms. Chlorine, a nonmetal, is on the more electronegative side of the periodic table. Sodium, a metal, is on the electropositive side and donates electrons to the chlorine atoms.

Step 1: $Na \rightarrow Na^+$ + electron (production of an Na^+ cation plus release of one electron)
Step 2: electron + $Cl \rightarrow Cl^-$ (released Na electron reacts with Cl to produce a Cl^- anion)
Overall: Na + ~~electron~~ + Cl $\rightarrow$ Na^+ + Cl^- + ~~electron~~

Notice that the electron produced in Step 1 is used in Step 2, so it is cancelled out in the overall reaction. (See the subsection on Ions in the Atomic Structure section - page 44.)

EXAMPLE:

What would happen if magnesium (Mg) atoms were bonding with Cl atoms instead?

Step 1: Mg → Mg^{2+} + 2 electrons (production of an Mg^{2+} cation plus release of two electrons)

Step 2: 2 electrons + 2 Cl → 2 Cl^- (the two released Mg electrons react with Cl to produce Cl^- anions)

Overall: Mg + ~~2 electrons~~ + 2 Cl → Mg^{2+} + 2 Cl^- + ~~2 electrons~~

Magnesium is in group 2 and has two valence electrons. When magnesium reacts with chlorine, each Mg atom donates two electrons. Chlorine is in group 17 and has seven valence electrons, so each Cl atom will only gain one electron. Therefore, two Cl atoms are needed to accept the two electrons from each Mg atom, making the formula $MgCl_2$.

Quick Fact

The periodic table can be used to predict the formulas of ionic compounds. Remember: all atoms want electron configurations like the noble gases.

In the $MgCl_2$ example, Mg wants to be like Ne. Mg can only do this by losing two electrons. Chlorine wants to be like Ar, which only requires one electron. Therefore two chlorine atoms are required to bond with one magnesium atom.

Here's the periodic table trick:

- Count two boxes backward from Mg to get to Ne. Give the 2 to the Cl.
- Count one box forward for Cl to get to Ar. Give that 1 to the Mg.
- The result is Mg_1Cl_2. Because we don't show the number one in formulas, we write $MgCl_2$.

COVALENT BONDING

Covalent bonds occur when valence electrons are shared between two nonmetal atoms, which have similar electronegativities and are close to one another on the periodic table. Compounds formed entirely from atoms that share electrons through covalent bonds are called **covalent compounds**.

- Covalent bonds create stable compounds if the sharing of electrons brings about a noble gas electron configuration for each atom (with eight valence electrons).
- In a covalent bond, one atom does not actually lose an electron in order for the other atom to gain an electron. Instead, the atoms **share** the electrons. Both atoms in a covalent bond gain electrons. Two atoms would not be able to share electrons if their electronegativities were very different, because one atom would attract the electrons much more strongly than the other.
- Each covalent bond contains one electron pair (two electrons).
- Nonmetal atoms generally have high electronegativity, meaning that they want to gain electrons, and also high ionization energy, meaning that they do not want to give up their own electrons. Nonmetal atoms tend to form covalent bonds because it allows them to share electrons, so they can gain electrons without giving up any of their own.

Quick Fact

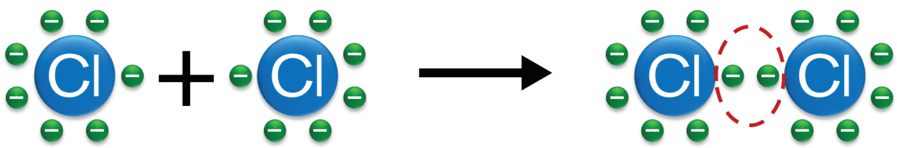
Hydrogen is an exception to the octet rule. A hydrogen atom is stable when it makes one bond (has two valence electrons), because it achieves the same electron configuration as the noble gas helium.

Think About It...

What type of covalent bond is found in diatomic oxygen? What about diatomic nitrogen? Use the periodic table to determine how many bonds oxygen and nitrogen tend to make. "See page 78."

EXAMPLE:

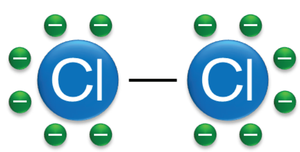
Look at the molecule of Cl_2 below. Chlorine is found on the third period of the periodic table and is part of the halogen group. Because this molecule is made up of two atoms that are the same, both atoms in the bond have the same electronegativity and the same ability to attract electrons. The two chlorine atoms share the electrons equally between them. Remember that only the outermost electrons participate in the bond. Chlorine's electron configuration is $1s^22s^22p^63s^23p^5$, so its outermost electrons are those in the third energy level: the $3s^23p^5$ electrons. Chlorine has a total of seven valence electrons, and it is these electrons that participate in the bond. The reaction can be shown as:



The two electrons inside the dotted oval (above right) are shared. Each chlorine atom now has access to eight electrons. Both atoms now have the same electron configuration as the noble gas in the same period, argon, and are therefore stable.

A single covalent bond contains two shared electrons. This means there is one covalent bond in a Cl_2 molecule (2 electrons shared, divided by 2 electrons in each bond = 1 bond).

- Two electrons that form a bond are shown as a line between the bonded atoms. Cl_2 is shown as:



- The bond that forms between the chlorine molecules to make Cl_2 is called a single covalent bond. Chemical compounds can also contain *double covalent bonds* and *triple covalent bonds*.
  - Single covalent bond (single bond): a covalent bond sharing only one pair of electrons (two electrons total) between two atoms (e.g. Cl_2).
  - Double covalent bond (double bond): a covalent bond sharing two pairs of electrons (four electrons total) between two atoms (e.g. O_2).
  - Triple covalent bond (triple bond): a covalent bond sharing three pairs of electrons (six electrons total) between two atoms (e.g. N_2).

Atoms do not have to be identical to form a covalent bond. A covalent bond can form between two nonmetals or between a nonmetal and a semimetal.

Quick Fact

Structures that show atomic symbols and either lines or dots for the valence electrons, such as the one pictured to the left, are called Lewis structures (see the section on Lewis Structures – page 81).

This name was given in honor of Gilbert N. Lewis for his contributions to bonding theory.

Think About It...

Why must atoms have similar electronegativities to form covalent bonds? What happens when atoms have very different electronegativities?

METALLIC BONDING

Metallic bonding occurs when metal atoms bond by contributing their electrons to a "sea" of shared electrons. This "sea" of electrons is shared among all of the bonded atoms in the entire structure.

- Metallic bonds are collective by nature, so a single metallic bond does not exist.
- In a metal, the valence electrons are shared among all the atoms. Each metal atom gives up its valence electrons, forming a "sea" of electrons.
  - The creation of an electron "sea" only occurs if there are no elements with high electronegativity (i.e. nonmetals) present to accept the electrons. Since there are no nonmetals to accept the electrons, there is no more stable place for the electrons to be than in the electrons sea, shared between all metal atoms.
  - Remember, metals often have low electronegativity and low ionization energy. This allows metal atoms to give up electrons easily. Metallic bonds occur when the Coulombic attraction keeping the electrons bound to the atom's nucleus is weaker than the electron's energy; the electrons have enough energy to break free.
- Metallic bonds can also form among elements that have higher ionization energies. These elements' atoms do not give up electrons to other substances easily.
  - Gold, cadmium, iridium, and platinum are metals with relatively high ionization energies. Atoms of gold will not give up electrons to other substances, but will come together to form strong metallic bonds.

Since electrons in a metallic compound are not held tightly to individual nuclei, the electrons are able to move more freely. Many properties of metals result from the high mobility of electrons in a metallic bond, as well as the ability of those electrons to move across the entire object.

- **Luster:** the ability to reflect light. Luster is why metals look shiny.
  - The large number of freely moving electrons in a metal absorb and re-emit light.
- **Electrical conductivity:** a measure of the rate at which electricity can travel through a material.
  - Metals have good electrical conductivity because their electrons can move easily throughout the metal.
- **Thermal conductivity:** a measure of the rate at which thermal energy can travel through a material.
  - Metals also have good thermal conductivity. As part of a metal is heated, the electrons become excited. The excited electrons then travel to the other side of the metal, carrying the thermal energy with them. Metals conduct thermal energy better than substances whose electrons cannot move freely. This is why cold metal feels colder to the touch than equally cold plastic or wood. The thermal energy in a person's hand is transferred to metal more quickly than it is transferred to wood, even if the difference in thermal energy (difference in temperature) between someone's hand and the wood is the same.
- **Malleability:** the ability of a metal to be flattened, shaped, or formed without breaking when pressure is applied. This includes the ability of a metal to be hammered into a thin sheet.
  - The mobility of electrons allows metal atoms to slide past one another when stress is applied. They do so without experiencing strong repulsive forces that would cause other materials to shatter.
- **Ductility:** the ability of a metal to be stretched into a thin wire or thread without breaking.
  - Like malleability, the mobility of electrons in a metallic bond allows the atoms to slide past one another as the metal is pulled and reshaped.

Quick Fact

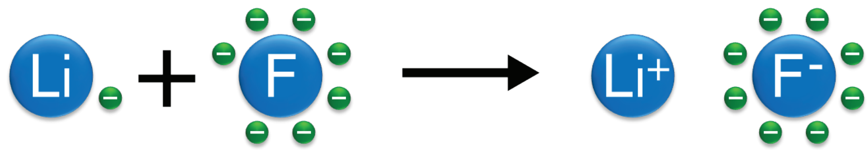
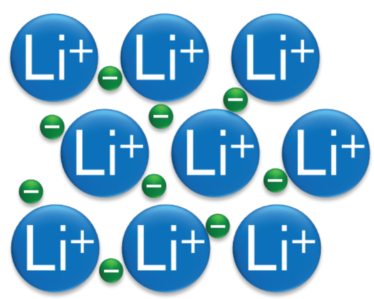
Silver and gold are precious metals because they are less reactive than most other metals and have a high luster. "Precious" refers to their high economic value.

Think About It...

In the movie ***A Christmas Story***, Flick is dared to touch his tongue to a metal flagpole in freezing temperatures. He takes the dare, and his tongue gets stuck to the metal. Why would this NOT have happened if the flagpole had been made of wood?

BONDING SUMMARY

- Ionic bonding is the result of one atom donating an electron to another atom so that both atoms complete their octets.
- Covalent bonding is the result of atoms that both need electrons, so they share electrons.
- Metallic bonding is the result of collectively shared electrons.

Ionic Bonding	
Covalent Bonding	
Metallic Bonding	

**In the atom images above, the electron cloud has been removed for easier visualization.*

NOTES

LEWIS STRUCTURES

Lewis structures are one way to represent chemical compounds. In the Lewis structure of a compound, chemical symbols are used to represent each atom in the compound. Bonds (lines) are drawn between symbols to show how electrons are shared. Dots represent valence electrons that are not shared, or "lone pairs" belonging to only one atom.

When atoms react, they create bonds to achieve a full octet of eight valence electrons (again, hydrogen and helium are exceptions—they are stable when they have two valence electrons). The **bonding rules** below determine the number of bonds that one atom of an element will make in a compound.

- **Gaining electrons:** when an atom is gaining electrons, the number of bonds it will make equals the number of electrons that the atom needs to complete its octet. In a covalent bond, both atoms gain electrons. In an ionic bond, the more electronegative atom gains electrons.

  Number of bonds = 8 – Number of valence electrons

  For example, fluorine is in group 17 and has seven valence electrons. According to the equation above, fluorine makes one bond because 8 - 7 valence electrons = 1 bond. Moving along period 2, oxygen makes two bonds, nitrogen makes three bonds, and carbon makes four bonds. Nonmetals tend to gain electrons as they are more electronegative.

- **Losing electrons:** when an atom is losing electrons, the number of bonds it will make equals the number of valence electrons that atom has. In ionic compounds, the less electronegative element loses all of its high-energy valence electrons to achieve the same electron configuration as the noble gas in the period above it.

  Number of bonds = Number of valence electrons

  In period 2 of the periodic table, lithium makes one bond and beryllium makes two bonds. Metals tend to lose electrons as they are less electronegative.

- Hydrogen atoms always make one bond, whether they are in an ionic or a covalent compound. Hydrogen atoms are never given a full octet because a hydrogen atom can hold only two electrons.
- Except in rare and unstable cases, carbon cannot have any lone pairs and will always make four bonds.

Think About It...
Why can't a hydrogen atom hold more than two electrons? What is the ground-state electron configuration of a hydrogen atom?

COVALENT COMPOUNDS

Covalent compounds are made up of one or more nonmetal atoms connected by covalent bonds. In the Lewis structure of a covalent compound, lines between atoms are used to represent the sharing of electrons (covalent bonds), just one line in the case of Br_2.

At normal room temperature, halogens like bromine exist as diatomic molecules. The Lewis structure of diatomic bromine, Br_2, a covalent compound, is shown below:

- The Lewis symbols of the individual bromine atoms are shown to the left of the arrow.
- The Lewis structure of the covalent compound Br_2 is shown to the right of the arrow.
- All of the black dots around each of the bromine atoms represent lone electron pairs belonging to that atom (each dot is one electron). The single line between the two bromine atoms represents a shared electron pair.
- The electron pair shared between the bromine atoms in Br_2 is a single covalent bond. The bond is made up of one electron from each bromine atom. Both electrons in the bond are shared equally, so that each bromine atom gains one electron and achieves an octet (eight valence electrons).

To count the number of valence electrons that one atom has in the Lewis structure of a covalent compound:

Valence electrons = (Number of electron dots around the atom) + (2 x Number of bonds the atom makes in the compound)

Each bromine atom in the Lewis structure of Br_2 has (6 electron dots) + (2 x 1 bond) = 8 valence electrons.

To draw the Lewis structure of a covalent compound:

1. Count the total number of valence electrons in the compound. This is the sum of the valence electrons of all of the atoms in the compound.
2. Represent each atom using its chemical symbol. Draw bonds between atoms according to the bonding rules on the previous page.
3. Count the number of valence electrons that each atom has after adding the bonds in step 2. Give each atom (besides hydrogen) a complete octet by adding electron dots until the atom has eight valence electrons.
4. Count the total number of valence electrons in the Lewis structure:

   Total valence electrons = Total number of electron dots + 2 x Total number of bonds

   The total number of valence electrons in the Lewis structure should be the same as the total valence electrons from step 1.

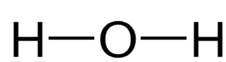
EXAMPLE:

To draw the Lewis structure of one molecule of water, begin by counting the total number of valence electrons in H_2O.

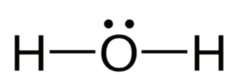
(1 valence electron per H atom) x (2 H atoms) =	**2 valence electrons from hydrogen**
(6 valence electrons per O atom) x (1 O atom) =	**6 valence electrons from oxygen**
One H_2O molecule:	**8 valence electrons**

One molecule of H_2O has a total of 8 valence electrons.

Next, draw bonds between the chemical symbols of hydrogen (H) and oxygen (O). Let's look at the bonding rules. Oxygen is in group 16, so it should make 8 — 6 valence electrons = 2 bonds. Hydrogen makes 1 bond. This gives us:



Each oxygen atom now has 2 x 2 bonds = 4 valence electrons. Oxygen needs 4 more electrons to complete its octet, so we add 4 electron dots around oxygen:



Remember, hydrogen does not need a full octet and is stable with only two valence electrons. Finally, count the total number of valence electrons in the Lewis structure.

Total valence electrons = (4 electron dots) + (2 electrons per bond) x (2 bonds)
Total valence electrons = 8 valence electrons

This is the same as the number of valence electrons we counted at the beginning! Therefore the image above is the correct Lewis structure for one molecule of H_2O.

Think About It...

What does the Lewis structure of the covalent compound NH_3 (ammonia) look like? How many bonds does one nitrogen atom tend to make?

IONIC COMPOUNDS

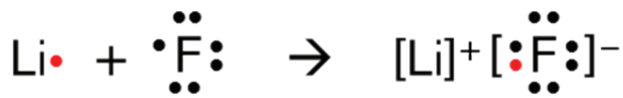
Ionic compounds are made up of two or more ions held together by ionic bonds. Unlike in covalent compounds, ionic compounds are not held together by shared electrons. Instead, ionic compounds are held together by the attraction between opposite charges (cations and anions). Because ionic compounds are a collection of ions, and not atoms held together by individual bonds, Lewis structures are not used as frequently to draw ionic compounds.

The Lewis structure for an ionic compound is simply all of the individual Lewis symbols for each of the ions in the compound.

To write the Lewis symbol of an ion from the chemical formula:

1. Start with the Lewis symbol of the neutral atom (see the subsection on **Lewis Symbols** - page 66).
2. Add or remove electron dots to show how many electrons the neutral atom has lost or gained.
3. Put the symbol in brackets, and add the charge as a superscript outside of the brackets.

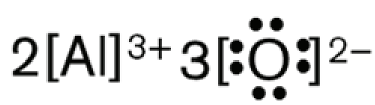
Lithium fluoride (LiF) is an example of an ionic compound:



- The neutral atoms of lithium and fluorine are shown to the left of the arrow. The Lewis structure of the ionic compound LiF is shown to the right of the arrow.
- Lithium, the less electronegative atom, donates one electron to fluorine, the more electronegative atom.
- The lithium cation and the fluorine anion are attracted to each other because of their opposite charges.
- Both lithium and fluorine reach a full outer energy level and the same electron configuration as a noble gas. Lithium's electron configuration goes from $1s^22s^1$ as a neutral atom to $1s^2$ as a 1+ cation, the same configuration as helium. Fluorine's electron configuration goes from $1s^22s^22p^5$ as a neutral atom to $1s^22s^22p^6$ as a 1— anion, the same configuration as neon.

Think About It...
Why do aluminum and oxygen combine in a 2:3 ratio? In what ratio would aluminum and fluorine combine?

Many ionic compounds are not formed in a 1:1 ratio, so coefficients can be used to show how many ions of each element are present. For example, aluminum and oxygen combine in a 2:3 ratio to form aluminum oxide, Al_2O_3. Aluminum oxide can be represented as shown below:



Quick Fact
Both rubies and sapphires are made of a mineral form of aluminum oxide called corundum. When small amounts of chromium are present in corundum, the mineral appears red and is called ruby. When small amounts of iron and titanium are present, the mineral appears blue and is called sapphire.

SECTION VII:
CHEMICAL REACTIONS

OBJECTIVES

- Identify the reactants and products of a chemical reaction.
- Identify exothermic and endothermic reactions.
- Understand rates of chemical reactions and the effects of catalysts.
- Describe and identify examples of types of chemical reactions.
- Describe the law of conservation of mass.
- Apply the law of conservation of mass to correctly balance chemical equations.
- Explain pH and describe substances as acidic or basic on the pH scale.
- Define and identify common acids, bases, and indicators.

A **chemical reaction** occurs when the atoms of one or more substances are rearranged to produce one or more different substances. As a result of a chemical reaction, new substances with new properties are formed.

- **Reactants:** the starting material or materials for a chemical reaction.
- **Products:** the substance or substances produced from a chemical reaction. Sometimes one or more of the products can be classified as byproducts.

In general, a chemical reaction will be represented as shown below:

Reactants → Products

EXAMPLE:

The chemical reaction between hydrogen and nitrogen is shown below:

$$3H_2 + N_2 \rightarrow 2NH_3$$

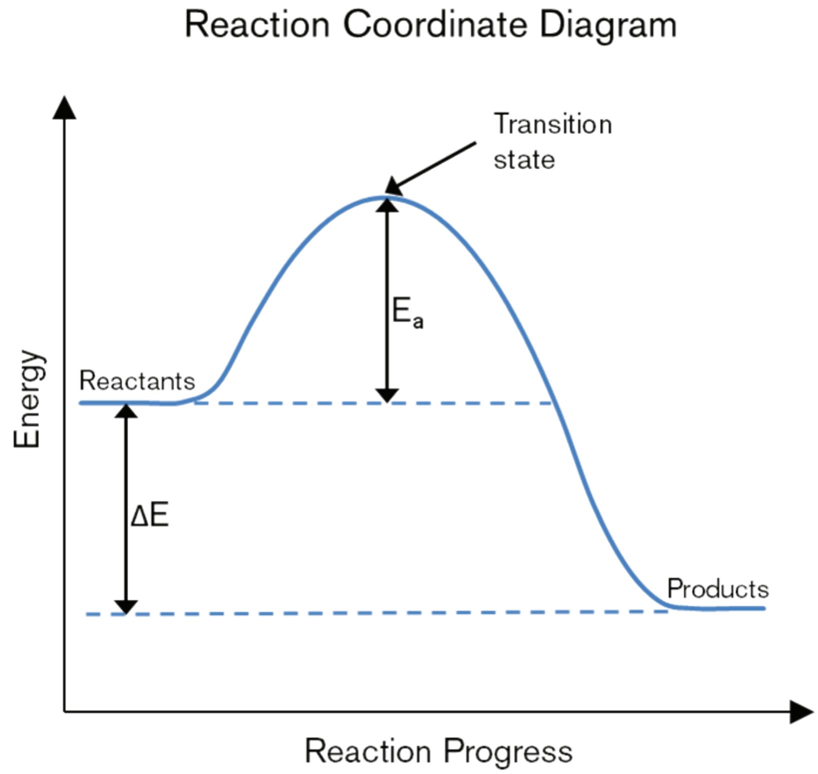
- **The hydrogen, H_2, and nitrogen, N_2, molecules are the reactants.**
- **The resulting ammonia, NH_3, is the product.**

VISUALIZING CHEMICAL REACTIONS

When a chemical reaction occurs, the reactants do not just change directly into the products. It takes time and energy for chemical bonds to be broken and made, and the reactants are often rearranged in multiple different ways as the atoms shift around to become the final product. The road that atoms and molecules take to get from starting materials to products is called the **reaction pathway.**

As the reactants change and bonds are broken and remade, the total energy of the reactants changes too. A **reaction coordinate diagram** plots the energy of the reaction—and all of the molecules and atoms involved—versus how far the reaction has progressed, as shown on the following page. When all of the molecules and atoms are lower in energy, they are more stable. Conversely, they are less stable when they are higher in energy. In general, chemical compounds try to move towards a state that is lower in energy because it is more stable.

Think of a reaction pathway as a hiking trail going over a mountain, and think of altitude (height) as the total energy of the reactants. The altitude changes moving along the trail, and a hiker has to pass through all of the different altitudes along the trail to get from the beginning of the trail to the end. Similarly, reactants have to progress along the reaction pathway, changing energy as they go, until they reach the final products.



- The initial flat portion is the energy of the reactants. The flat portion at the end is the energy of the products.
- ΔE represents the overall change in energy. It is the difference between the starting energy and the final energy.

$$\Delta E = \text{(Energy of the products)} - \text{(Energy of the reactants)}$$

- E_a represents the **activation energy**. Activation energy is the minimum amount of energy needed to start a chemical reaction.
  - The reactants pass through a state that is much higher in energy in order to get to the products, called the "transition state." In the transition state, the bonds in the reactants are in the process of breaking and the bonds in the products are in the process of forming. The transition state is the top of the hill (highest in energy) in the reaction coordinate diagram.
  - Activation energy is the amount of energy required to get the reaction "over the hill," or to start the reaction by overcoming the energy barrier. It is the energy needed to go from the reactants to the transition state.

$$E_a = \text{(Energy of the transition state)} - \text{(Energy of the reactants)}$$

  - All chemical reactions need some amount of activation energy. The activation energy is needed to break existing bonds so that new bonds can be made.

Quick Fact

A spark provides the energy needed to start a combustion reaction and set wood on fire. The thermal energy (heat) of the spark is greater than the activation energy of the combustion reaction.

The activation energy (E_a) and the change in energy (ΔE) above are independent of one another. The change in energy depends only on the starting energy and the final energy (the reactants and the products) and is not affected by energies along the way.

ENERGY OF CHEMICAL REACTIONS

All chemical reactions involve some overall change in energy, because the products have a different amount of energy than the reactants.

Think of a chemical reaction as a hiking trail over a mountain. The difference in height between the beginning of the trail and the top of the mountain is the activation energy. The energy change of the reaction is the difference in height between the beginning of the trail and the end of the trail. The path a hiker takes to cross the mountain won't change their altitude at the beginning or their altitude at the end. These two altitudes (the beginning and the end) are completely independent of the height of the mountain and the path that a hiker takes to get across.

Some chemical reactions require the input of energy and others release energy, depending on whether the products are higher or lower in energy than the reactants.

Quick Fact
A common example of an exothermic reaction is burning wood in a wood stove. Wood combines with the oxygen in the air to produce carbon dioxide, water, light, and heat.

- **Exothermic reactions:** chemical reactions that produce energy, often in the form of heat, light, or sound.

  The reactants themselves lose energy, and that energy is released to the environment around the reaction. The products of an exothermic reaction are more stable (lower in energy) than the reactants.

A + B → C + D + energy

EXAMPLE:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l) + \text{energy}$$

In the exothermic reaction above, methane and oxygen react to produce carbon dioxide, water, and heat.

- **Endothermic reactions:** chemical reactions that require the constant input of energy from an outside source to occur.

  The reactants gain energy by taking energy from their surroundings, often in the form of heat or light. An endothermic reaction would feel cold to the touch because it absorbs heat from its environment. The products of an endothermic reaction are less stable (higher in energy) than the reactants.

A + B + energy → C + D

EXAMPLE:

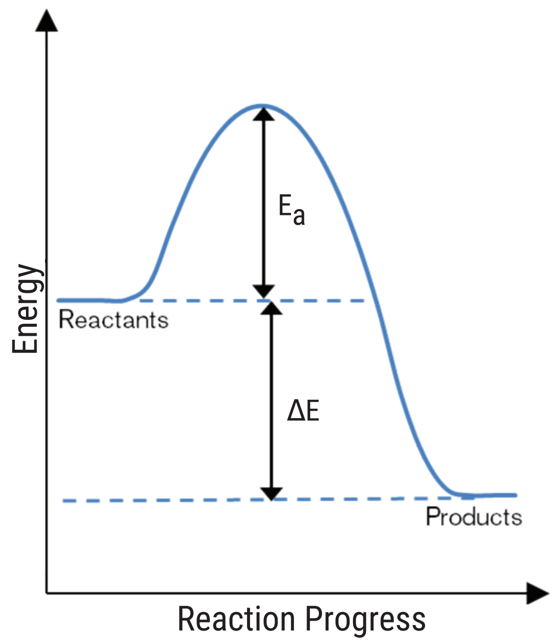
$$\text{energy} + 2Al_2O_3(s) \rightarrow 4Al(s) + 3O_2(g)$$

In the endothermic reaction above, energy is added to bauxite (aluminum oxide) to produce aluminum metal and oxygen gas.

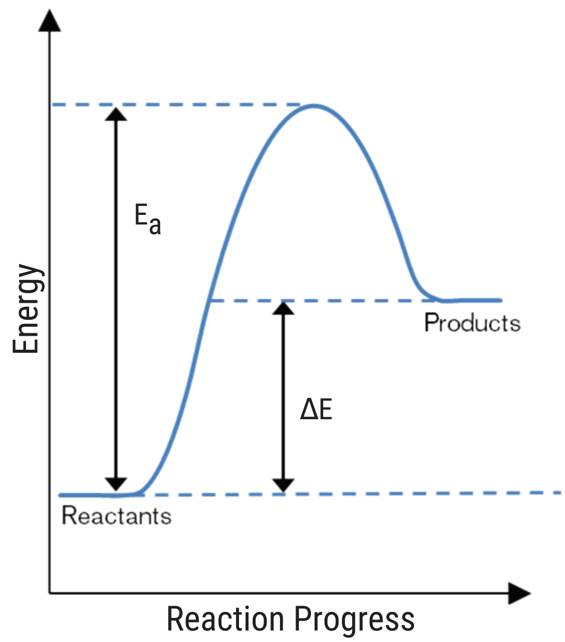
Quick Fact
A common example of an endothermic reaction is the process of photosynthesis. During photosynthesis, plants use the energy from the sun to convert carbon dioxide and water into glucose and oxygen.

The reaction coordinate diagrams below show the difference between exothermic and endothermic reactions.

Exothermic Reaction



Endothermic Reaction



- In the exothermic reaction above, the products are at a lower energy level than the reactants. The difference, ΔE, is the amount of energy released from the reaction.
  - Since ΔE = (Energy of the products) – (Energy of the reactants), ΔE is negative. It is lost by the reactants.
- In the endothermic reaction above, the products are at a higher energy level than the reactants. This difference, ΔE, is the amount of energy that has to be put into the reaction.
  - The product energy is greater than the reactant energy, so ΔE is positive. It is gained by the reactants.
- Just because a reaction requires energy in order to start does not mean that it is an endothermic reaction. The exothermic reaction above requires a certain amount of energy (E_a) to get over the energy barrier, but releases more energy during the reaction than it takes to get started. Chemists often initiate exothermic reactions, adding a small amount of energy, to produce much more energy.

Quick Fact

Diamond and graphite are both forms of pure carbon. Graphite is more stable than diamond at normal room temperature and pressure, so the reaction of diamond turning into graphite is exothermic and should spontaneously occur. The reason that diamonds do not turn into graphite is because the activation energy for the reaction is extremely high, making it almost impossibly difficult for the reaction to occur.

Think About It...

What does the reaction coordinate diagram for diamond turning into graphite look like? How do the energy of the reactants, the energy of the products, and activation energy compare to one another?

RATES OF CHEMICAL REACTIONS

Different reactions occur at different rates (or speeds), and even the same reaction can occur at different rates under different conditions. **Chemical kinetics** is the field of science that studies the rates of chemical reactions. Kinetics answers the question: "how fast will this reaction occur?"

To understand reaction rates, it is helpful to first understand what actually happens during a chemical reaction. Three things must be true for a chemical reaction to occur:

1. Particles of the reactants must collide with (or run into) each another. "Particle" here just means one unit, so a particle of a reactant could be an atom, an ion, a molecule, or a formula unit.
2. The particles must have enough energy to react—this usually means the particles must be going at least a certain speed. "Enough energy" means at least the activation energy. If the particles are not moving fast enough, they will not have enough energy to break old bonds and form new bonds when they collide.
3. The particles must have the proper orientation to react.

Particles are always moving around randomly, so sometimes they will collide with one another. If the particles collide with enough energy and the right orientation, they react. The frequency of particles colliding with each other successfully and reacting determines the reaction rate. This is called **collision theory**.

In general, the rate of a chemical reaction can be increased in a few different ways:

1. **Concentration:** A higher concentration of the reactants increases the number of particles in the same amount of space, so it is more likely that particles will run into each other. Think of particles as people. People are more likely to run into each other in a crowded room. Generally, increasing the concentration of the reactants increases the reaction rate.
2. **Temperature:** Remember, temperature is a measure of kinetic energy, or how fast the particles in a substance are moving. When particles are moving faster, they are more likely to collide. People running around in a room are more likely to run into each other than people walking. The particles also have more energy (on average), so when two particles collide they are more likely to have enough energy to react.
3. **Catalysts:** A catalyst is a substance that changes the rate of a reaction. Catalysts are most often used to increase the reaction rate (to make the reaction happen more quickly) by making it easier for the reaction to take place. The identity and amount of a catalyst is the same at the beginning and at the end of a reaction.
   - A catalyst usually lowers the activation energy by changing the reaction pathway to avoid the highest-energy state.
   - There is a lower energy barrier for the reaction to occur, so it is more likely that particles will have enough energy to react when they collide.
   - Think of a hiking trail again. A catalyst is like a shortcut across the mountain so hikers don't have to climb all the way to the top.

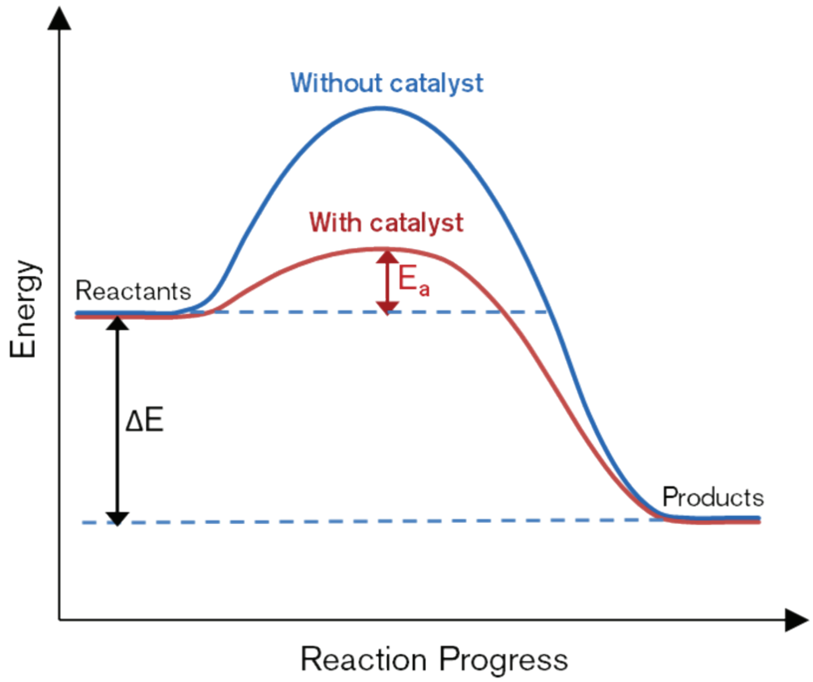
Quick Fact

For the average reaction occurring at room temperature, raising the temperature by 10 °C approximately doubles the reaction rate.

Quick Fact

Humans need catalysts! Your body burns fuel (in the form of food), just like a car's engine burns fuel. Your body doesn't require the amount of heat that a car needs in order to burn fuel, but it does require a lot of energy. There are special catalysts in the body called enzymes that help humans burn fuel at normal body temperature. Without catalysts, the activation energies of the reactions that burn fuel in the human body would be too high.

The diagram below illustrates the effect of a catalyst on a reaction. With a catalyst, the "energy hill" that a reaction has to climb is much lower.



Quick Fact
Car exhaust contains environmental pollutants. Automobiles use catalysts such as palladium and platinum to convert these pollutants into less toxic chemicals and improve air quality.

Quick Fact
The slowest known biological reaction would take 1 trillion years without a catalyst. However, this reaction is essential to creating our DNA. With enzymes, the reaction can occur in only 10 milliseconds.

Changing the activation energy changes the rate of the reaction. However, it does not change the energy of the products or reactants, as seen above, so ΔE remains the same. The rate of a reaction is independent of the overall change in energy.

NOTES

TYPES OF CHEMICAL REACTIONS

In the chemical reactions described in this section, the letters A, B, C, and D are used to represent chemical elements or compounds.

SYNTHESIS (OR COMBINATION) REACTION: a chemical reaction in which smaller molecules combine to form a larger one. As shown below, two or more reactants (A and B) combine to form a product (AB).

$$A + B \rightarrow AB$$

EXAMPLE:

$$2H_2\,(g) + O_2\,(g) \rightarrow 2H_2O\,(l)$$

The (g) and (l) after the compounds correspond to the phases of each of those compounds. A (g) means that compound is a gas, (l) means a liquid, and an (s) means a solid. You might also see (aq), which stands for aqueous solution – or a liquid mixture of a compound where water is the solvent.

Think About It...
The reaction to the left could be used for hydrogen-powered cars. There is plenty of oxygen in the air to fuel the reaction, but where would the hydrogen come from?

DECOMPOSITION REACTION: a chemical reaction in which a compound (AB) breaks apart into two or more products (A and B). It is the opposite of a synthesis reaction. Most decomposition reactions need an outside source of energy to take place.

$$AB \rightarrow A + B$$

EXAMPLE:

$$2HgO\,(s) \xrightarrow{\Delta} 2Hg\,(l) + O_2\,(g)$$

In this decomposition reaction, mercury(II) oxide (HgO) splits into liquid mercury and oxygen gas. The small triangle above the arrow means the reaction needs energy (usually in the form of heat) to take place.

Quick Fact
If you wanted to say what was occurring in the reaction to the left, you would describe it as: "Two mercury oxide molecules decompose into two mercury atoms plus one oxygen gas molecule."

SINGLE DISPLACEMENT (OR REPLACEMENT) REACTION: a chemical reaction in which a reactant (A) takes the place of some component of a compound (BC). In doing so, a new compound (AC) is made, and a separate product (B) is released.

$$A + BC \rightarrow AC + B$$

EXAMPLE:

$$Mg\,(s) + 2HCl\,(aq) \rightarrow MgCl_2\,(aq) + H_2\,(g)$$

This displacement reaction happens when a piece of solid (s) magnesium metal is combined with some aqueous (aq) hydrochloric acid. When these reactants combine, they produce two products: a liquid solution called aqueous magnesium chloride and hydrogen gas (g).

Think About It...
How would you describe the displacement reaction to the left?

DOUBLE DISPLACEMENT (OR REPLACEMENT) REACTION:

a chemical reaction between two compounds, AB and CD, in which component of one reactant trades places with component of another reactant. The elements are rearranged to form two or more different compound products, AD and CB.

AB + CD → AD + CB

EXAMPLE:

$$Fe_2O_3\,(s) + 6HNO_3\,(aq) \rightarrow 2Fe(NO_3)_3\,(aq) + 3H_2O\,(l)$$

In this double displacement reaction, iron(III) oxide combines with nitric acid. The reaction produces iron(III) nitrate and water.

Quick Fact

The reaction shown to the left could also be written as:
AB + CD → DA + BC
A molecule composed of a single D atom and a single A atom can be written as either DA or AD, but scientists have adopted a rule that says to place the more electropositive element first. The products will be written as AD and CB, if A and C represent cations.

BALANCING CHEMICAL EQUATIONS

When a chemical reaction occurs, it can be described by a **chemical equation**, which uses chemical symbols and formulas to describe a reaction. A chemical equation uses chemical symbols to show the reactants and products involved. A chemical equation can also show the physical states of the reactants and products, as well as the involvement of heat, light, or radiation. Unlike mathematical equations, the two sides are separated by an arrow to show that the reactants form the products.

CONSERVATION OF MASS

Law of conservation of mass: matter cannot be created or destroyed, although it may be changed. According to this law, the mass of the reactants must equal the mass of the products. (Nuclear reactions are an exception.)

Because all matter is made of atoms, the law implies the conservation of the number of atoms in a chemical reaction. Therefore, although atoms may be rearranged, they cannot be not lost during the reaction.

What does conservation of atoms mean? The number of atoms of each element on the reactants side (left side of the arrow) must equal the number of atoms of each element on the products side (right side of the arrow). When the atoms on both sides are equal, the equation is balanced. A balanced equation demonstrates conservation of atoms. It also shows the lowest whole-number ratio of products to reactants.

- If a hydrogen atom goes into a reaction, it has to appear somewhere in the products of the reaction.
- Likewise, if three hydrogen atoms appear on the reactant side of a chemical equation, three must appear on the product side.

EXAMPLE:

Methane interacts with oxygen in air as shown in the reaction below:

$$CH_4\,(g) + O_2\,(g) \rightarrow CO_2\,(g) + H_2O\,(l)$$

As written above, the equation correctly indicates that methane and oxygen combine to form carbon dioxide and water. However, this reaction violates conservation of matter. There are more oxygen atoms on the right than on the left, and more hydrogen atoms on the left than the right. The correctly balanced equation for the reaction looks like this:

$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(l)$$

Quick Fact

Diatomic elements must always have a subscript of 2 in pure form. In the reaction shown to the left, oxygen must be present as O_2 and not just O. The elements that are always diatomic at room temperature in elemental form are H_2, O_2, F_2, Br_2, I_2, N_2, and Cl_2.

To determine the number of atoms of one element in a chemical formula:

- Multiply the number in front of the chemical formula by the subscript number on that atom in the chemical formula. The number in front of the chemical formula is called a coefficient. It indicates how many of that molecule or atom there are. The coefficient of a molecule applies to all of the elements in the molecule's formula.
- The number one is never written. CH_4 stands for $1C_1H_4$.
- To make sure the equation is balanced correctly:
  - Write the number of each type of atom on the reactant side.
  - Write the number of each type of atom on the product side.
  - Compare the numbers.

Quick Fact

Balancing chemical equations is like putting a puzzle together. You may not be able to tell which pieces fit where, so you may have to try a few different ways before you find a good fit. With chemical equations, you may not be able to immediately see which numbers will work to balance the equation, so you have to experiment!

EXAMPLE:

$$CH_4\,(g) + 2O_2\,(g) \rightarrow CO_2\,(g) + 2H_2O\,(l)$$

Reactant Side of Equation	Product Side of Equation
C: 1 × 1 = 1	C: 1 × 1 = 1
H: 1 × 4 = 4	H: 2 × 2 = 4
O: 2 × 2 = 4	O: (1 × 2) + (2 × 1) = 4

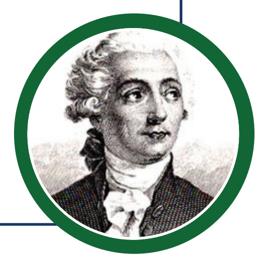
The number of each type of atom is the same in the reactants as it is in the products, therefore the reaction is balanced.

HISTORY: **ANTOINE LAVOISIER** (1743–1794)

Antoine Lavoisier proposed the first version of the law of conservation of mass. His law stated that during an ordinary chemical change, there is no noticeable increase or decrease in the quantity of matter.

Lavoisier is known as the father of modern chemistry. He changed chemistry from a qualitative to a quantitative science.

He recognized and named oxygen. He also discovered the role oxygen plays in combustion.



BALANCING CHEMICAL EQUATIONS

1. Write the unbalanced equation and see which elements are not balanced (not equal). For example, below is the unbalanced equation for ethane reacting with oxygen to produce carbon dioxide and water.

$$C_2H_6\,(g) + O_2\,(g) \rightarrow CO_2\,(g) + H_2O\,(l)$$

Reactant Side of Equation	Product Side of Equation
C: 1 × 2 = 2	C: 1 × 1 = 1
H: 1 × 6 = 6	H: 1 × 2 = 2
O: 1 × 2 = 2	O: (1 × 2) + (1 × 1) = 3

- There is 1 fewer carbon atom, 4 fewer hydrogen atoms, and 1 more oxygen atom in the products than there are in the reactants. This equation is not balanced.

2. Balance the equation. An easy way to start is to balance the elements that appear in only one reactant and one product (carbon and hydrogen in this reaction). Once those elements are balanced, move on to the elements that appear in multiple reactants or products (oxygen in this reaction). To test each change that you make in the equation multiply the different atoms and molecules on each side by different amounts based on their coefficients.

- To get the same number of carbon atoms on both sides, multiply CO_2 (on the right side) by 2. This is shown by placing a 2 in front of CO_2.

$$C_2H_6\,(g) + O_2\,(g) \rightarrow \underline{2}CO_2\,(g) + H_2O\,(l)$$

- Be sure to multiply all atoms by the coefficient. Therefore, $2CO_2$ means there are 2 carbon atoms and 4 oxygen atoms. ***Do not change the subscripts***. Changing the subscripts changes the ratio of different elements in the compound, which makes it a different molecule altogether. In this case, 1 molecule of CO_2 is made of 1 carbon atom and 2 oxygen atoms. The coefficient of 2 in front of CO_2 says that the reaction produces 2 molecules of CO_2.

- To get the same number of hydrogen atoms on both sides, add a coefficient of 3 in front of H_2O on the right side, making it $3H_2O$.

$$C_2H_6\,(g) + O_2\,(g) \rightarrow 2CO_2\,(g) + \underline{3}H_2O\,(l)$$

- Now there are 2 carbon atoms and 6 hydrogen atoms on each side. However, the number of oxygen atoms is not the same. There are 2 on the left side and 7 on the right side (4 from CO_2, 3 from H_2O).

- Add a coefficient of 3.5 in front of O_2 on the left side, making it $3.5O_2$.

$$C_2H_6\,(g) + \underline{3.5}O_2\,(g) \rightarrow 2CO_2\,(g) + 3H_2O\,(l)$$

This equation has the same number of each type of atom on both sides, but is not quite done.

Quick Fact
Often the best way to balance an equation is by trial and error, and testing a few different numbers until one set of coefficients works.

Quick Fact
A properly balanced equation must have the lowest possible whole number for each coefficient. For example $4C_2H_6\,(g) + 14O_2\,(g) \rightarrow 8CO_2\,(g) + 12H_2O\,(l)$ would not be the final balanced equation, because all of the coefficients can be divided by 2.

3. A balanced equation should not contain decimals. In the equation above, the oxygen on the left is written as having a half molecule. Because there is no such thing as half an oxygen molecule, we must eliminate it from the equation. We do this by multiplying all the coefficients by two.

$$2C_2H_6\,(g) + 7O_2\,(g) \rightarrow 4CO_2\,(g) + 6H_2O\,(l)$$

This equation is the properly balanced equation for the reaction.

ACIDS, BASES, AND pH

ACIDS

Substances that release hydrogen ions (H^+) when dissolved in water are acids. An acidic solution has an excess of hydrogen ions (H^+).

- Acids often donate H^+ ions to bases.
- Acids dissociate (break down) into ions in solution, making them able to conduct electricity. Some acids are corrosive in nature, and have the ability to dissolve some metals.
  - Most acids can react with metals to produce metal salts and hydrogen.

Quick Fact

The word "acid" comes from the Latin term "acidus," which means sour. Substances with a sour taste (like lemon juice) are usually acidic. Refer back to Naming Acids subsection in Chemical Bonding and Formulas (page 73) to refresh on how to name different acids.

EXAMPLE:

When magnesium comes into contact with hydrochloric acid, the acid reacts with the metal. The reaction produces magnesium chloride (a salt) and hydrogen gas.

$$Mg\ (s) + 2HCl\ (aq) \rightarrow MgCl_2\ (aq) + H_2\ (g)$$

BASES

Substances that either release hydroxide ions (OH^-) when dissolved in water or that accept H^+ ions from acids are bases. A basic solution has an excess of OH^- ions.

- Bases often donate OH^- ions to acids.
- Bases feel slippery to the touch and are often used to make soaps. However, strong bases such as drain cleaner can harm human skin.
- Although the term "alkali" is often used as a synonym for base, they are not the same thing. **Alkalis** are a type of base made of ionic salts of an alkali metal (Group1) or an alkaline earth metal (Group2). *All alkalis are bases, but not all bases are alkalis*.

Quick Fact

Bases typically have a bitter taste and, like acids, can conduct electricity when in solution.

EXAMPLE:

Calcium carbonate ($CaCO_3$) and soda lye (NaOH) are bases that are also alkali salts. Ammonia (NH_3) is a base but *not* an alkali.

THE pH SCALE

The pH of a solution indicates how acidic or basic it is by measuring the concentration of H^+ ions in a solution. The **pH scale** is used to measure the acidity of a solution.

- Acids release hydrogen ions (H^+) when dissolved in water. Thus, the acid content of a solution is based on the concentration of hydrogen ions in the solution. When a lot of hydrogen ions are released into a solution (high concentration of hydrogen ions), that solution is very acidic.
- The pH scale is the tool used to indicate the concentration of hydrogen ions in a solution.
- Usually, substances in aqueous solution range from 0 to 14 on the pH scale. pH values do not have units.
  - Substances in aqueous solution with a pH value less than 7 are acids. The lower the pH value, the more acidic a substance is. A substance with a pH of 1 is more acidic than a substance with a pH of 5 (though both are acidic).
  - Substances in aqueous solution with a pH value greater than 7 are bases. The higher the pH value, the more basic a substance is. A substance with a pH of 13 is a stronger base than a substance with a pH of 10 (though both are basic).

Quick Fact

Negative pH: some very strong acids may have a pH lower than 0. For example, concentrated hydrochloric acid, HCl, may have a pH of zero or less than zero.

– Pure (distilled) water has a neutral pH of 7.0. A neutral substance is neither acidic nor basic. Water has an equal number of hydrogen (H^+) ions and hydroxide (OH^-) ions, giving it a neutral pH.

$$H^+ + OH^- \rightleftharpoons H_2O$$

– Small changes on the pH scale actually mean large changes in acidity. An increase of just one pH unit indicates that the concentration of H^+ ions (and the acidity) has increased by a factor of ten. For example, the concentration of H^+ ions in a solution with a pH of 5.0 is ten times that in a solution with a pH of 6.0; the solution with pH 5.0 is ten (10^1) times more acidic. Similarly, a solution with a pH of 3.0 is 1,000 (10^3) times more acidic than a solution with a pH of 6.0.

Quick Fact

Clean rain usually has a pH of 5.6, which is slightly acidic because of the carbon dioxide naturally present in the atmosphere. Rain measuring less than 5 on the pH scale is abnormally acidic, and is called *acid rain*.

The table below lists some common acids and bases on the pH scale. All of the substances whose pH is less than the pH of water (pictured above water on the table) are acidic. All of the substances whose pH is greater than the pH of water are basic.

	Substance	Approximate pH	Indicator Paper Color*
Acids (pH < 7.0)	**Sulfuric acid, battery acid**	**0.8–1.5**	
	Stomach acid	**1.0–2.0**	
	Lemon juice, cola	**2.3–2.5**	
	Vinegar	**2.9**	
	Apple juice, orange juice	**3.3–3.8**	
	Coffee	**5.0–5.5**	
	Milk	**6.5**	
Neutral	**Pure water**	**7.0**	
Bases (pH > 7.0)	**Human blood**	**7.4**	
	Sea water	**8.0**	
	Baking soda solution	**8.5–9.0**	
	Milk of magnesia	**10.5**	
	Household ammonia	**11.5–12.0**	
	Bleach	**12.5**	
	Liquid drain cleaner	**13.5–14.0**	

*See the subsection on **Indicators** - page 97.

STRENGTH OF ACIDS AND BASES

Acids and bases may be strong or weak depending on how well an acid or base produces ions in water. Many things will affect the strength of an acid or a base.

ACIDS

- A strong acid produces many hydrogen ions. A weak acid produces fewer hydrogen ions. As a result, indicator paper and litmus paper reveal slightly different colors depending on the strength of the acid (see the subsection on **Indicators** - page 97).
- The chemical equation of an acid, HA, dissociating (producing hydrogen ions) is shown below:

$$HA\ (aq) \rightleftharpoons A^-\ (aq) + H^+\ (aq)$$

- For some acids, the strength of an acid may be affected by the size of the anion produced when the hydrogen is released into water (see the section on **Ions** - page 44). **Within a group, acid strength increases as atomic radius increases moving *down* the periodic table.**
  - Larger anions are more stable, so they are more easily separated from the hydrogen ion and the corresponding acid is stronger (produces more H^+ ions). Hydroiodic acid ($HI_{(aq)}$) is a stronger acid than hydrofluoric acid ($HF_{(aq)}$) because the iodide ion ($I^-_{(aq)}$) is larger than the fluoride ion ($F^-_{(aq)}$), and therefore more stable. Binary acids (made from hydrogen and one other element) increase in strength going down a group on the periodic table.

Think About It...
Like acids, metallic substances can also conduct electricity. What do they have in common? How do acids conduct electricity differently than metals?

- Electronegativity also affects acid strength (see the subsection on **Electronegativity** - page 59). A more electronegative atom more strongly attracts electrons away from hydrogen atoms in solution, so more hydrogen atoms lose an electron to become H^+ cations. The more electronegative the element bonded to hydrogen in an acid, the stronger the acid. For example, hydrofluoric acid ($HF_{(aq)}$) is more acidic than the base ammonia ($NH_{3(aq)}$) because fluorine is more electronegative than nitrogen. **Within a period, acid strength increases as electronegativity increases moving from *left to right* across the periodic table.**
- Strong acids include hydroiodic acid (HI), hydrobromic acid (HBr), hydrochloric acid (HCl), sulfuric acid (H_2SO_4), and nitric acid (HNO_3).

BASES

- Strong bases act in a manner similar to strong acids, producing hydroxide ions instead of hydrogen ions. The equation of a base, BOH, dissociating looks like this:

$$BOH(aq) \rightleftharpoons B^+(aq) + OH^-(aq)$$

- Strong bases include sodium hydroxide (NaOH), potassium hydroxide (KOH), and lithium hydroxide (LiOH).
- Bases can also produce OH^- ions by accepting H^+ ions. In the equation below, a base, B, accepts an H^+ ion from water:

$$B(aq) + H_2O(l) \rightleftharpoons HB^+\ (aq) + OH^-\ (aq)$$

  - Ammonia, NH_3, is an example of a base that accepts H^+ ions, as shown in the equation below:

$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+\ (aq) + OH^-\ (aq)$$

INDICATORS

Indicators are substances that change color at a specific pH. They provide a way to determine approximately how acidic or basic a solution is. Some common qualitative indicators are:

- **Litmus paper** turns red in an acidic solution and blue in a basic solution.
- **Phenolphthalein** solution changes from colorless to pink for a pH greater than 8.2.
- **Bromothymol Blue (BTB)** turns yellow in acidic solutions and blue in basic solutions.

To get more accurate, quantitative pH measurements, scientists use an instrument called a pH meter.

Try It...

Try making your own pH indicator solution at home by extracting the purple pigment (anthocyanin) from purple cabbage.

Quick Fact

Certain foods and flowers act as indicators. Cherries, beets and purple cabbage appear red in acidic solutions but turn blue or purple in basic solutions. The flowers of hydrangea plants are blue in acidic soil but pink or white in basic soil.

NOTES

SECTION VIII:
RADIOACTIVITY AND NUCLEAR REACTIONS

OBJECTIVES

- Define radioactivity and radioisotopes.
- Explain half-life and use it in calculations.
- Identify common radioactive elements and describe their properties.
- Describe the difference between nuclear fission and nuclear fusion.
- Identify human-made elements and their location on the periodic table.

Elements tend to exist in multiple forms, called isotopes. Remember, isotopes are atoms of the same element that contain different numbers of neutrons. Isotopes of the same element have the same atomic number, but different mass numbers (see the subsection on **Isotopes** - page 44).

Isotopes of one element have similar chemical properties to each other and undergo similar reactions. However, since the isotopes differ in atomic mass, their physical properties are not exactly the same. Different isotopes of the same element often undergo chemical reactions at different rates.

EXAMPLE:

Remember that hydrogen can exist as one of three isotopes (protium, deuterium, and tritium). The lightest isotope, protium, tends to undergo chemical reactions at the fastest rate.

Quick Fact

Carbon-12 is the most common form of carbon. It was adopted in 1961 as the standard for defining all atomic weights.

Carbon-13 is non-radioactive and is frequently used for isotopic labeling studies. These studies follow how a carbon atom goes through specific reactions.

Carbon-14 is used in a process called carbon dating. It takes 5,730 years for half of the carbon-14 nuclei in a sample containing carbon to decay. This period of time is its halflife. Scientists use the predictable decay of carbon-14 to determine the age of organic materials up to 50,000 years old. Carbon dating is useful for studying artifacts left behind by ancient cultures.

RADIOACTIVITY

Radioactivity is the spontaneous breakdown of an unstable nucleus in an atom. When a radioactive atom decays, it releases radiation in the form of electromagnetic radiation and/or particles (page 100).

- **Radioisotopes:** The isotopes of an element that are unstable and therefore radioactive.

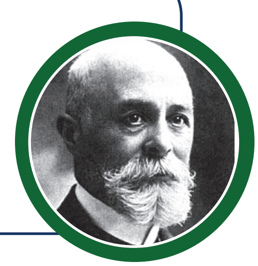
The **half-life** of an isotope is the time it takes for one-half of the nuclei present in a sample to undergo radioactive decay.

- After one half-life, 50% of the original sample will remain.
- After two half-lives, 25% of the original sample will remain, and so on.

HISTORY: **HENRI BECQUEREL** (1852–1908)

In 1896, French physicist Henri Becquerel accidentally discovered radioactivity while investigating phosphorescence in uranium salts.

The SI unit for radioactivity, the becquerel (Bq), is named after him.



HISTORY: **MARIE CURIE** (1867–1934)

Marie Curie discovered that the element thorium was "radioactive," a term she created. The same year, a German scientist named Gerhard Schmidt also made the same discovery about thorium.

Curie, along with her husband Pierre, discovered the radioactive elements polonium and radium.

In 1903, the Curies and Henri Becquerel were awarded the Nobel Prize in physics for the discovery and exploration of natural radioactivity. In 1911, Curie received her second Nobel Prize in chemistry for isolating radium and determining its atomic weight. She was the first woman to receive a Nobel Prize and the only woman, to this day, to receive two Nobel Prizes.

Po

POLONIUM

Atomic #84

Polonium was discovered by Marie and Pierre Curie in 1898. The element was named after the country Poland, where Marie Curie was born.

CHARACTERISTICS:

- Is a very rare natural element, found in extremely small amounts in uranium ores.
- Is mainly used as a source of neutrons, generally by combining it with beryllium.
- Has specialty uses in eliminating static electricity in machinery and removing dust from photographic film.

Polonium has over 25 known isotopes. Its most common isotope, Po-210, has a half-life of only 138 days. The radioactive decay of Po-210 produces lead-206 and a lot of energy (140 watts per gram).

Rn

RADON

Atomic #86

Radon is produced by the radioactive decay of the element radium.

CHARACTERISTICS:

- Is radioactive; the isotope with the longest half-life is radon-222 with a half-life of only four days.
- Is a colorless radioactive gas at a normal room temperature of about 70–75 ºF.
- Glows with a yellow color when cooled to its solid state.
- Is emitted naturally, in some regions, from soil and rocks and can sometimes build up in homes.

The World Health Organization estimates that radon is responsible for up to 14% of all lung cancer cases. Radon test kits are available to check for radon accumulation in homes, especially basement levels.

Ra

RADIUM

Atomic #88

Radium was discovered by Marie and Pierre Curie in 1898. Its name comes from the Latin word "radius" meaning "ray."

CHARACTERISTICS:

- Is a highly reactive metal.
- Is a brilliant, white metal in pure form but blackens when exposed to air.
- Occurs naturally in the environment from the decay of uranium and thorium.

Its most stable isotope, radium-226, has a half-life of about 1,600 years.

Pure radium and some of its compounds glow in the dark. As a result, radium was used in the mid-1900s in a luminous paint on the hands and numbers of watches to make them glow in the dark. However, this practice stopped when the risks of radium exposure became known.

The radioactive decay of an unstable nucleus may release several types of radiation, including alpha radiation, beta radiation, and gamma radiation.

ALPHA (α) RADIATION (ALPHA PARTICLES): Alpha particles are composed of two protons and two neutrons, which is identical to the composition of a helium nucleus. When an atom undergoes alpha decay, it loses two protons and two neutrons to form an alpha particle (a helium-4 nucleus). The atom's atomic number decreases by two, and its mass number decreases by four.

- Alpha radiation travels only a very short distance through air. It cannot penetrate skin or even a thin sheet of paper.
- Alpha particles are not radioactive (they do not decay farther). After losing their energy, they attract two electrons to become helium atoms.

EXAMPLE:

Uranium-238 has 92 protons and 146 neutrons. When uranium-238 undergoes alpha decay, it loses two protons and two neutrons to produce an alpha particle and thorium-234 (90 protons and 144 neutrons).

BETA (β) RADIATION (BETA PARTICLES): radiation composed of high-velocity electrons emitted from an unstable nucleus. When an atom undergoes beta radiation, a neutron loses a negative charge and becomes a proton after emitting a high velocity electron. The atom's atomic number increases by one and its mass number stays the same.

- Beta radiation can travel several meters through air but is stopped by solid materials.
- Beta particles can penetrate human skin, but clothing often helps to block most beta particles.
- Sometimes the release of a beta particle is not enough to get rid of the extra energy in an unstable nucleus. In this case, the nucleus often releases the rest of the excess energy in the form of gamma rays.

GAMMA (γ) RADIATION (GAMMA RAYS): high-energy photons in the form of electromagnetic radiation. Gamma radiation comes from the energy stored through holding the nucleus and subatomic particles together, similar to the energy stored in chemical bonds. Gamma radiation on its own does not cause the identity of an atom to change.

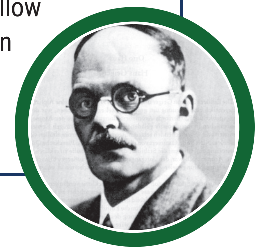
- Gamma radiation is able to travel many meters in air. It easily penetrates most materials, including several centimeters through human tissue.
- Gamma radiation frequently accompanies the emission of alpha and beta radiation.

Quick Fact

Radiation can be used in medicine to treat disease and to look inside the body to diagnose medical problems. Radiation has proven useful to kill cancer cells by causing mutations (defects) in the DNA of those cancer cells, thus preventing the cancerous cells from being able to grow and divide.

HISTORY: **JOHANNES WILHELM GEIGER** (1882–1945)

Johannes Wilhelm "Hans" Geiger was a German physicist known for his work on radioactivity. In 1928, with fellow physicist Walther Müller, he developed a device to measure radioactive emissions. The device became known as the **Geiger Counter**. The two worked to improve the device's sensitivity, performance, and durability. As a result, they created a tool that is used in laboratories around the world today.



NUCLEAR ENERGY

Nuclear reactions are changes that occur in the structure of atomic nuclei. The energy that results from nuclear reactions is called nuclear energy or atomic energy. Nuclear energy is released from atoms in two different ways: nuclear fission and nuclear fusion.

NUCLEAR FISSION: a nuclear reaction that occurs when an atomic nucleus splits into two smaller parts (nuclei), usually about the same size. When this happens, vast amounts of energy are released.

- Uranium nuclei can be split easily by bombarding them with neutrons.
- Once a uranium nucleus is split, multiple neutrons are released. Each of these neutrons initiates other fission reactions, resulting in a chain reaction.

Quick Fact

The atomic bomb developed by the United States during World War II used a nuclear fission reaction beginning with the radioactive isotope uranium-235. Nuclear fission is also used in nuclear power plants to generate energy.

U

URANIUM

Atomic #92

Uranium was first identified in pitchblende ore in 1789. It was named after the planet Uranus, which had been discovered around that time.

CHARACTERISTICS:

- Is the heaviest naturally occurring element on Earth, except for minute traces of neptunium and plutonium.
- Is highly radioactive, toxic, and carcinogenic.
- Has over 16 isotopes, all of which are radioactive.

Uranium's radioactivity was first detected by Henri Becquerel in 1896. Today, it is primarily used in nuclear fuels and explosives. Uranium, specifically the isotope uranium-235, is the principle element used in nuclear reactors and in certain types of atomic bombs.

Uranium compounds have been used for centuries as additives in glass. They give glass interesting yellow and green colors and a fluorescent effect.

NUCLEAR FUSION: a nuclear reaction that occurs when the nuclei of two atoms join to make a larger nucleus. Again, energy is given off in this reaction.

- Nuclear fusion only occurs under very hot conditions.
- The sun and all other stars create energy (in the form of heat and light) through nuclear fusion. In the sun, hydrogen nuclei fuse to make helium.

Quick Fact

The hydrogen bomb uses nuclear fusion. Hydrogen nuclei fuse to form helium. In the process, they release huge amounts of energy and create a massive explosion.

HISTORY: **ENRICO FERMI** (1901–1954)

Enrico Fermi was an Italian physicist most known for his work on beta decay, the development of the first nuclear reactor, and his contributions to the development of quantum theory. He worked on the Manhattan Project during World War II to produce the atomic bomb, though he warned of its power.

In 1938, Fermi won the Nobel Prize in physics for his work on radioactivity. Element 100 (fermium) was named after him.

Pu

PLUTONIUM

Atomic #94

Plutonium was discovered in 1940 at the University of California at Berkeley. It was named after the dwarf planet Pluto. The element's discovery, however, was kept classified by the government until 1946.

CHARACTERISTICS:

- Is a very heavy, silvery metal in pure form.
- Is a rare radioactive element; found in minute amounts (one part per trillion) in uranium ore.
- Used mainly as a fuel for nuclear reactors and nuclear bombs.

Plutonium was produced in the United States during World War II as part of the Manhattan Project to create the atomic bomb. Over one-third of the energy produced in most nuclear power plants comes from plutonium.

NOTES

HUMAN-MADE ELEMENTS

All of the elements with atomic numbers greater than 92 are known as transuranic or transuranium elements. They do not occur naturally on the earth. Most of these heavier elements have been made by bombarding the element uranium with neutrons or other particles in a cyclotron.

Many of the human-made, transuranic elements are named for important chemists or physicists. Curium (atomic number 96), for example, is named after Marie Curie and her husband, Pierre Curie. Other human-made elements are listed in the table below:

Atomic #	Element	Symbol	Named for ...
99	Einsteinium	Es	**Albert Einstein**, the famous scientist who developed the Theory of Relativity.
101	Mendelevium	Md	**Dmitri Mendeleev**, who developed the modern periodic table.
102	Nobelium	No	**Alfred Nobel**, who commercialized dynamite and endowed the Nobel Prizes for physics, chemistry, medicine, literature, and peace.
103	Lawrencium	Lr	**Ernest O. Lawrence**, who invented the cyclotron.
104	Rutherfordium	Rf	**Ernest Rutherford**, who helped develop the modern understanding of the atomic nucleus.
106	Seaborgium	Sg	**Glenn Seaborg**, who was known for his work in the separation and purification of plutonium. He was also known for proposing the "Actinide" concept for reorganizing the periodic table.
107	Bohrium	Bh	**Niels Bohr**, who proposed a model of atomic structure that explained the role of the electron.
109	Meitnerium	Mt	**Lise Meitner**, who is known for her work on the discovery of nuclear fission.

Quick Fact

In December 2015, the International Union of Pure and Applied Chemistry (IUPAC) verified the discovery of four new transuranic elements. The addition of elements 113, 115, 117, and 118 completed the seventh row of the periodic table.

Quick Fact

The new elements were named nihonium (element 113), moscovium (115), tennessine (117), and oganesson (118). Nihonium is the first element to be named by researchers in Asia—the common Japanese name for Japan is "nihon."

SECTION IX:
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 round or cone shaped 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.
  - The wide surface area of the flask’s bottom allows liquids to be heated quickly.

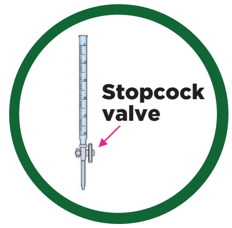
- Florence flask (boiling flask): a round flask that may have a rounded or flat-bottomed base.
  - A liquid contained in a Florence flask will heat evenly because the round shape spreads the heat around the flask.
  - Florence flasks tend to be stronger than other flasks. They are often used to boil 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 at which the flask should be filled. The meniscus of the liquid in the flask should match with this line (see Graduated cylinder discussion on page 105). 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.

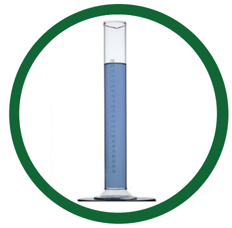
- Test tubes are used to hold or heat small amounts of a substance during laboratory experiments.
- Test tubes are usually held upright using clamps or special test tube holders.

MEASURING LIQUID VOLUMES



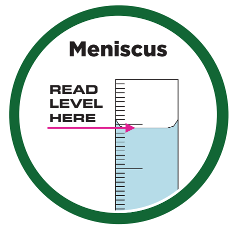
Buret (burette): a long glass cylinder used to accurately measure and dispense a specific volume of liquid. The cylinder is open at the top, while the bottom comes together into a tip from which the liquid flows. A stopcock valve is attached to the bottom, above the tip, which controls the amount of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

- Burets are often used for titrations, 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 at right).



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 place the solid into the cylinder. After the solid is completely 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 carefully place 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.

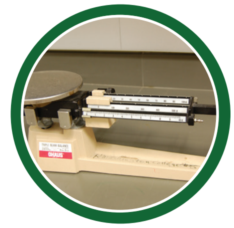
Quick Fact

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?

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 the measurements on the three beams 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.

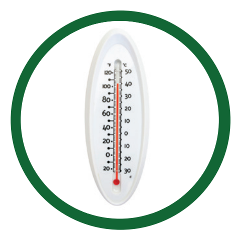
- The measuring pan of an analytical balance is enclosed inside the device to prevent dust from collecting on the pan and to prevent air currents in the room from affecting the measurement.

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 if measuring on a scale).
- Some balances provide an option for automatically "taring" the vessel so that the balance reads zero with the vessel placed on the measuring pan. Then, the mass (or weight if measuring on a scale) 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 sealed graduated glass tubes. They have a bulb at one end that holds a fluid that expands as it is heated. Above the fluid, the tube is typically filled with an inert dry gas such as nitrogen at or below atmospheric pressure. 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.

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.

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.

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.

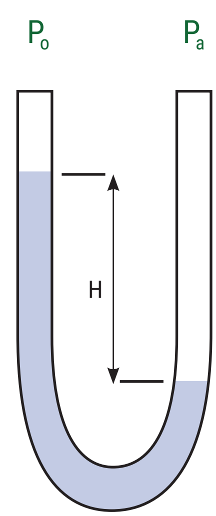
More recently, alcohol replaced mercury in thermometers. Like mercury, alcohol has a freezing point below the freezing point of water. Mercury was replaced with alcohol because it is dangerous to humans. If a mercury thermometer breaks it can be a hazard, so alcohol is a safer alternative.

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.

- 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.



P_o = reference pressure (open to atmosphere)

P_a = test pressure

H = difference in the height of the fluid on the two sides of the manometer

- 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 elastic metal tube, called a "Bourdon" tube.

- A Bourdon tube uncoils or straightens like a spring when pressure inside it 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.

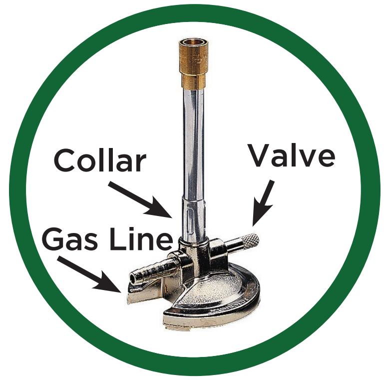
- Liquid is drawn up into a pipette by suction. A vacuum is created in the pipette. When the pipette is placed into a liquid, the vacuum creates suction. The suction causes the liquid to move up into the pipette.
- **Pasteur pipette:** a long, skinny tube with a bulb at one end. These pipettes are like 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.)

NOTES

SECTION X:
LABORATORY & CHEMICAL SAFETY

OBJECTIVES

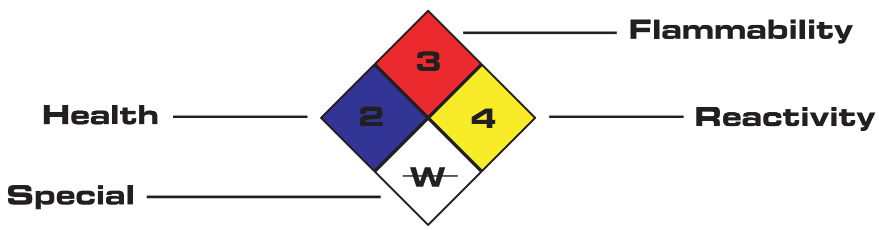
- Explain the importance of chemical safety and where to find chemical safety information.
- Identify common chemical safety and protective equipment symbols.
- List and describe basic laboratory safety guidelines and tips.

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*.

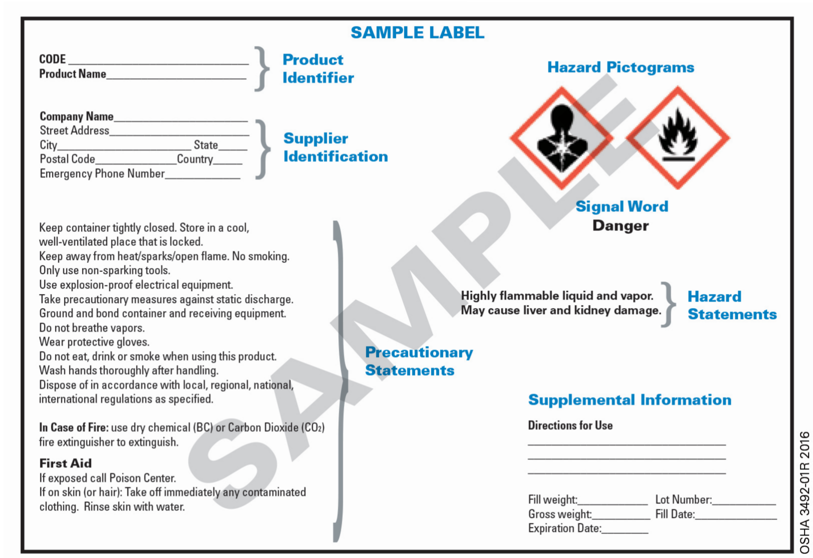


*Image Source: "Hazard Communication Standard Labels." Occupational Health & Safety Administration. U.S. Department of Labor. 2016. https://www.osha.gov/Publications/OSHA3492QuickCardLabel.pdf

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.

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.

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.

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.

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 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.

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: ttps://www.osha.gov/hazcom. Be sure to ask your teacher or educator if you would like more information.

NOTES

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.

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

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

Quick Fact

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

GENERAL SAFETY RULES

Scientists take special care when working in the lab and performing experiments. They are careful to choose the safest chemical to work with, 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, nose 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.

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.

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.

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?

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.

NOW YOU'RE READY FOR THE CHALLENGE! GOOD LUCK!

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