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CHEMISTRY CONCEPTS IN ACTION

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SECTION I:
LABORATORY SEPARATIONS

OBJECTIVES

- Define a separation process and provide examples.
- Identify and distinguish between different types of separation processes.
- Describe specific examples of the uses of different separation processes.

When conducting experiments, scientists often need to separate parts of a mixture. Separation processes are used in a wide variety of ways, including to get clean drinking water from natural water supplies that contain various salts and minerals. Separation processes can use both physical and chemical means to separate the parts of a mixtures. (See the section on Physical and Chemical Separations from *The Core of Chemistry*.)

- **Separation process:** a process that separates a mixture into its components based on differences in their properties.

DISTILLATION

Distillation separates the components of a liquid mixture based on the differences in boiling points of the mixture's components. Reference the diagram on the following page to see how a distillation apparatus is set up.

- During distillation, a liquid mixture (starting solution) is heated until the temperature reaches the boiling point of the component of the mixture with the lowest boiling point. That component then vaporizes and forms a gas.
- The pure vapor (gas) then moves through a tube called a condenser. The condenser cools the vapor, which causes it to condense into its pure liquid form. It then drips into another container (receiving flask) and is collected. The purified liquid is called the distillate.

Distillation is often used to separate the *solvent* from the *solute* in a liquid solution. The solvent will vaporize and collect in the new container. The solute or solutes will be left behind in the original container. This process is more commonly known as **simple distillation**.

EXAMPLE:

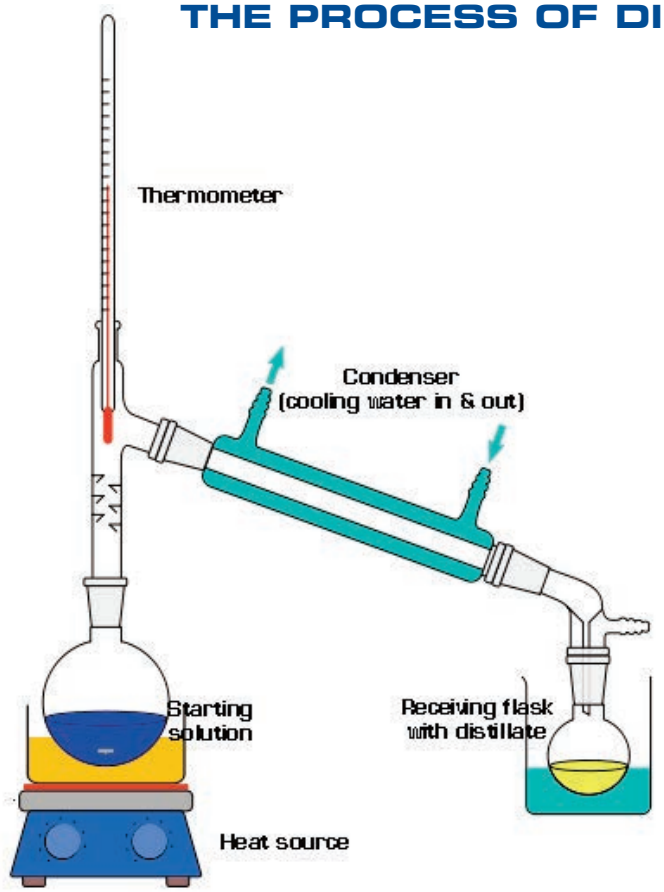
Distillation can be used to separate a solution of salt and water. When the solution is heated to the boiling point of pure water (approximately 100 °C), the water vaporizes. Because salt, NaCl, has a much higher boiling point (approximately 1400 °C), the salt is left behind. The water vapor flows through a condenser and cools. Upon cooling, the water vapor condenses into pure liquid water and is collected in a separate container.

Distillation can be used to purify sea water. Heating sea water to the boiling point of pure water causes the water to vaporize. When the water vaporizes, the salts and other components of the sea water are left behind, and purified water condenses in the receiving flask.

Quick Fact

Distillation is a great way to purify water. Distilled water can be collected as the distillate, leaving impurities in the aqueous solution that stays behind.

THE PROCESS OF DISTILLATION



DISTILLATION DEVICE

The image at left shows one type of distillation set up.
(Not all distillation processes are set up in the same way.)

During distillation, the heat source heats the starting solution. When the starting solution reaches the boiling point of one of the liquid components in the solution, that liquid will vaporize. The vapor will move up the tube and into the condenser. The condenser will cool the vapor to liquid form. The purified liquid (distillate) will then flow into the receiving flask.

QuickFact

Fractional distillation is a type of distillation process commonly used in modern refineries.

Fractional distillation can be used to separate components of a mixture with similar boiling points. Temperature changes allow each part to vaporize independently. The component with the lowest boiling point will evaporate first and then condense - this sample is collected before the next component vaporizes.

For example, if a small sample of ethanol (boiling point 78.4 °C) were added to the salt water solution described on the example in the previous page, the starting solution could be heated to 78.4 °C for the purified ethanol to evaporate. The water (boiling point 100 °C) and the salt (boiling point 1400 °C) would remain in the solution because a temperature of 78.4 °C is not high enough for those components to evaporate. Once all of the ethanol evaporates and is collected from the receiving flask, the temperature of the remaining mixture can be raised to 100 °C to allow purified water to evaporate.

CENTRIFUGATION AND DECANTATION

Centrifugation separates a mixture based on the different densities of its components. The mixture is spun at high speeds around a center axis in a laboratory centrifuge. The centrifugal force causes higher density particles to separate from lower density particles.

- During centrifugation, a test tube containing a sample of a mixture is placed inside a centrifuge. The tube is spun around to increase the effective gravitational force. This causes the denser particles to collect at the bottom of the tube, farthest from the center of the spinning centrifuge. Once the particles collect, the remaining solution is quickly and carefully poured from the top of the test tube (decanted) or removed with a pipette.
- Centrifugation is often used to separate denser solids, such as a precipitate, that are suspended in a liquid.
- Centrifugation is an important research technique. It is often used in biochemistry, cellular and molecular biology, and medicine.

Quick Fact

Centrifugation is used to separate raw whole milk into various milk products. The process separates the heavy cream from the skim milk.

This process is also used to separate the components of blood for certain blood tests. Centrifugation causes the dense red blood cells to collect at the bottom of a test tube. The white blood cells and platelets form the next layer, and the lighter plasma rests on top.

Decantation is a process of quickly and carefully separating components of a liquid mixture based on density. Decantation can be used to separate two liquids with different densities or a mixture of a liquid and a denser solid. In the case of a mixture of a liquid and a solid, the denser particles in the mixture (*sediment*) settle to the bottom of the container. Then, the liquid is carefully poured from the container to make sure the sediment remains.

- Decantation is often used after centrifugation or after a precipitation reaction creates a sediment or precipitate. A small amount of the liquid is often left in the container to ensure that none of the solid particles escape.
- Decantation is similar to filtration, but there are some major differences. For example, filtration uses a barrier (such as filter paper) to catch the solid particles. Decantation does not use a barrier material. In filtration, the particles can be dispersed throughout the liquid. Decantation requires the solid particles to settle to the bottom of the container, which often requires more time than filtration. Whether filtration or decantation is used depends on the sample that the scientist is trying to separate.

CRYSTALLIZATION

Crystallization is the process by which solid crystals are formed from a homogeneous solution.

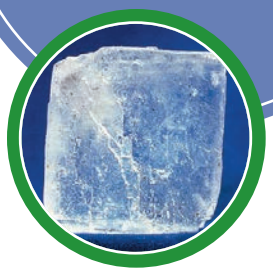
- Crystals (or crystalline solids) contain particles arranged in a repeating pattern. Crystals can be separated from a solution by vaporizing the solvent. The distillation of salt water leaves behind salt crystals.
- Crystals can also form from a **supersaturated** solution (see the subsection on Chemicals by Volume—Solutions). As the supersaturated solution cools, the solubility of the solute *decreases*. This decrease in solubility causes the solution to be unstable. A seed crystal is added to the solution so that the solute crystallizes out. (A seed crystal is a small or single crystal that serves as a starting surface from which a larger crystal can grow.) The crystals will grow in number and size and can be removed by a solid-liquid separation method, such as filtration.

EXAMPLE:

You can create a saturated solution of sugar water by adding sugar to water until sugar crystals can no longer be dissolved. More crystals can be dissolved into the saturated solution by heating it. (The solubility of solid solutes tends to increase as temperature increases.) As you let the solution cool slowly, a *supersaturated* solution is formed. If a seed crystal is added or if there is a jagged surface in the container, excess sugar will begin to crystallize out of the solution.

Quick Fact

Decreasing the temperature of a solution can reduce the solubility of a solute. Solubility is also affected by changes in the pH of a solution.



Many scientists also use crystallization to purify solids in solution. In a suitable solvent, the pure solid will form crystals and any contaminants or extra unwanted components will stay dissolved in the solution. Crystallization is often used to remove salts from solutions, as well as in the production of pharmaceuticals.

ABSORPTION AND ADSORPTION

Absorption is a process by which matter takes in another substance. The absorbed substance is spread throughout the absorbing matter and becomes a part of its structure.

- A kitchen sponge soaking up water is an example of absorption.

Adsorption is a process by which a substance binds to the surface of a solid or liquid. The adsorbed substance (called the adsorbate) gathers on the surface but does not enter the solid or liquid.

- During this process, the adsorbate creates a film on the surface of the solid or liquid adsorbent.
- Charcoal is often used in water purification systems because it can adsorb many contaminants. The adsorbed contaminants become bound to the surface of the solid charcoal.

SOLVENT EXTRACTION AND CHROMATOGRAPHY

Solvent extraction is a process of removing a soluble component from a mixture by adding a certain solvent. This process utilizes the differences between the solubility of the components of the mixture. The component to be separated should be able to dissolve easily in the solvent.

EXAMPLE:

Solvent extraction is commonly used for recovering vegetable oil. Vegetable oil is produced by flaking and crushing the oilseed. Some of the oil can be recovered directly from the crushing process. However, much of the oil remains in the seed and is recovered by contact with a solvent (hexane). The oil is highly soluble in hexane and can be separated from the crushed seed for further processing.

EXAMPLE:

Solvent extraction can also be used to remove certain chemical substances from soil. Substances like oil and grease will stick to soil and cannot be washed away with water. A different solvent must be used to separate the oil or grease from soil.

Quick Fact

A coffee machine uses hot water as a solvent to remove the soluble parts of the coffee. As a result, the insoluble parts of the coffee grounds are left behind. This form of extraction is often called solid-liquid extraction.

Chromatography is a group of separation processes used to separate and analyze complex mixtures based on differences in their structure or composition.

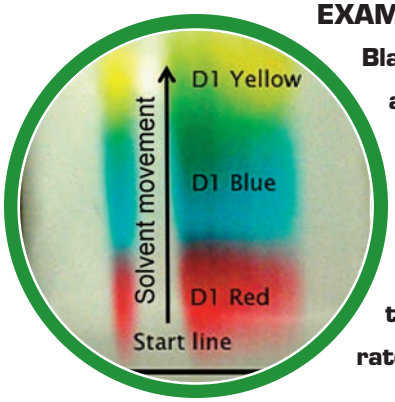
During chromatography, a mixture (usually a liquid) moves over a stationary material (like paper), called the *stationary phase*. The mixture that flows over the stationary material is called the *mobile phase*. Components of the mobile phase flow through the stationary phase at different rates because of their different affinities for the stationary and mobile phases, allowing the components to separate.

There are various types of chromatography, including gas chromatography, column chromatography, and thin layer chromatography. Paper chromatography is a method that can be demonstrated easily in a classroom using black ink.

Quick Fact

Chromatography is often used in law enforcement, specifically in forensic science. Chromatography techniques are used to test for drugs, poisonous substances, and traces of explosives.

EXAMPLE:



Black ink is a mixture of many different colors that can be separated from one another using a solvent and chromatography paper. A drop of black ink is placed near the bottom of a piece of chromatography paper. Then, the bottom edge of the paper is placed in water or another solvent. The paper will begin to absorb the solvent. As the solvent moves up the paper, it carries the mixture of black ink up through the paper as well. As the ink flows through the paper, the different color components move through the paper at different rates and separate. This leaves bands of color along the paper.

SECTION II:
LABORATORY ANALYSIS

OBJECTIVES

- Distinguish between qualitative and quantitative analysis.
- Identify and describe types of qualitative analysis.
- Identify and describe types of quantitative analysis.

Analytical chemistry focuses on understanding the chemical composition (makeup) of matter. Analytical chemists design experiments and use instruments that measure chemical compositions and structures. Most analytical procedures for mixtures begin with a separation process, such as filtration, distillation, extraction, or chromatography, so that each component may be analyzed independently.

QUALITATIVE VERSUS QUANTITATIVE ANALYSIS

Analytical chemistry measurements may be qualitative or quantitative.

- **Qualitative analysis** determines whether or not a certain substance is present in a sample. Qualitative analysis shows *what* is in a sample and often involves classifying or categorizing data.
- **Quantitative analysis** determines the amount of a certain substance in a sample. Quantitative analysis shows *how much* of something is in a sample.
  - Quantitative data are usually represented by numbers with scientific units, while qualitative data are not.

Think About It...

Analytical chemistry is used in many different jobs in all areas of science. Can you think of jobs that use analytical chemistry?

TYPES OF QUALITATIVE ANALYSIS

Scientists use different qualitative analysis techniques based on the type of substance they are trying to identify in a sample.

FLAME TESTS

A **flame test** is used to determine which elements – specifically, which metal ions – are present in a mixture.

- During a flame test, a clean wire is dipped into a solution or powder containing a metal and placed into a burner flame. The heat from the flame excites the metal ions, causing them to emit visible light. Different metals ions produce certain characteristic colors. For example, sodium creates a bright yellow flame, boron creates a bright green flame, and copper creates a blue flame.
- Several metals ions produce the same flame color. Some compounds, on the other hand, do not cause any color change.

Quick Fact

Sodium is present in many compounds. In order to determine other metals that might be present in a compound, scientists often view the flame through a special colored glass. Blue cobalt glass can filter out the yellow color produced by sodium. This filtering effect allows scientists to see only the color produced by the other metal.

SPECTROSCOPY

Spectroscopy is used to determine the molecular structure (through electronic and vibrational energy levels) and the chemical composition of a substance. It identifies the way the substance's atoms absorb and emit energy in the form of light.

- A spectrometer can be used to record the spectrum of light emitted (or absorbed) by a certain substance. Scientists can then use this light to determine the chemical composition of the substance, because atoms emit or absorb light with wavelengths (and therefore colors) specific to each element. These emissions or absorptions of light are called characteristic "spectral lines." Groups of atoms in a molecule also give off characteristic lines.

Quick Fact

Spectroscopy is used by astronomers to determine the chemical makeup of stars.

Continuous Spectrum

(no characteristic lines)

Emission Spectral Lines

Absorption Spectral Lines

- Different types of spectroscopy used in laboratories include IR (infrared) spectroscopy, nuclear magnetic resonance (NMR), Raman spectroscopy, and UV/VIS (ultraviolet/visible) spectroscopy.
- Some types of spectroscopy can be used as quantitative tools as well.

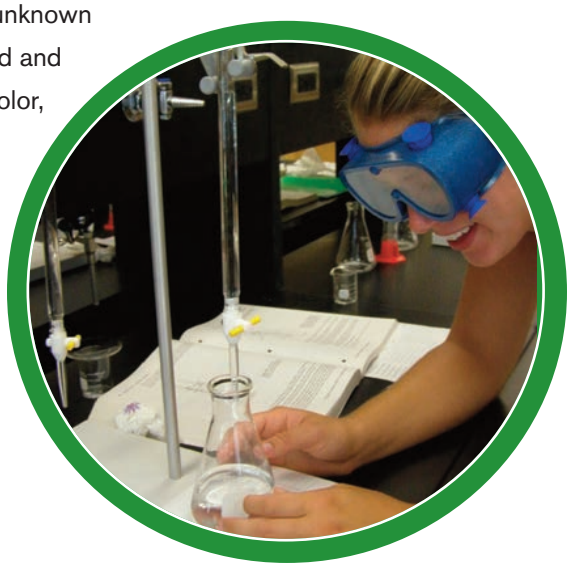
TYPES OF QUANTITATIVE ANALYSIS

Scientists use different quantitative analysis techniques to measure the amount or the concentration of a certain substance in a sample.

TITRATION

Titration is an analytical method used to determine the concentration of a substance in a solution. During a titration, a solution with a known concentration (the **titrant**) is added to a solution that has an unknown concentration and a reaction occurs. The completion of the reaction usually results in a change of color in the solution, often due to the addition of an indicator.

- To conduct a titration, a known volume of the solution of unknown concentration is poured into an Erlenmeyer flask. The titrant, known to react with the solute in the solution with unknown concentration, is added to a buret. Once the buret is positioned over the Erlenmeyer flask, the titrant is added in small amounts to the solution with unknown concentration until the chemical reaction is complete. The completion of the reaction is often accompanied by a color change in the solution.
- Once the reaction takes place, the volume of titrant needed to produce the reaction can be determined. The concentration of solute in the solution can then be calculated.
- Titration is useful in determining the concentration of acid or base in a solution. When the concentration of a base (used as a titrant) is known, for example, it can be added to an acid solution with an unknown concentration. An indicator can also be added to solution of unknown concentration. When the base is added, the acid is neutralized and the pH of the solution changes. The indicator then changes color, signaling that a reaction has finished (see Acids, Bases, and pH in Chemistry Connections).



GRAVIMETRIC ANALYSIS

Gravimetric analysis is used to determine the amount of a substance by measuring a change in mass. A certain component of a mixture is removed, and then the mass of the remaining components is measured. The mass of the remaining components can then be subtracted from the total mass of the initial sample to give the mass of the substance that was removed.

- Precipitation is often used to separate a solid sample from the solution to be weighed.

Quick Fact

A type of gravimetric analysis can be used to determine the amount of water in a substance. How? Weigh the substance. Then, heat it until all the water evaporates. Next, weigh the substance again. With that information, you can determine how much water it contained.

NOTES

SECTION III:
CHEMICAL QUANTITIES

OBJECTIVES

- Define relative atomic mass.
- Identify the quantity of a mole and how it relates to the mass of atoms.
- Explain concentration and how to determine the concentration of a combined solution.
- Define saturation and supersaturation.
- Distinguish between polar and nonpolar solvents and solutes.
- Describe important physical properties of solutions.

CHEMICALS BY MASS

A single atom weighs very little. The mass of a hydrogen atom is only about 0.000 000 000 000 000 000 000 002 grams. Even though atoms are small, scientists still need to know the mass of single atoms of different elements. In 1961, scientists started using carbon-12 as the standard atom for comparing the masses of all other types of atoms.

- The mass of carbon-12 was defined as 12 **atomic mass units (amu),** because carbon-12 has 6 protons and 6 neutrons. Remember, protons and neutrons have almost the same mass.
- All other atomic masses were determined with reference to the weight of the carbon-12 atom.
  - **Relative atomic mass (A_r):** the weighted average mass of all of an element's isotopes compared with one-twelfth the mass of one atom of carbon-12 (see the section on Isotopes from *The Core of Chemistry*).

$$A_r = \frac{\textit{weighted average mass of isotopes of an element}}{\frac{1}{12} \times \textit{mass of 1 atom of carbon-12}}$$

or

$$A_r = \frac{\textit{weighted average mass of isotopes of an element}}{\textit{1 amu}}$$

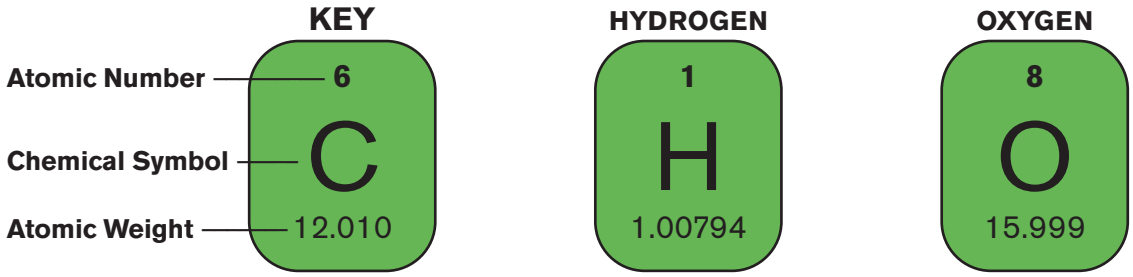
  - The relative atomic mass or atomic weight of each element is given on most periodic tables.
  - For most elements, the relative atomic mass is close to a whole number, so a whole number is often used for approximate calculations.

Quick Fact

A mass spectrometer is used to determine the relative masses of atoms (as compared to carbon-12). The instrument separates ions to determine the percentage of each isotope present. These percentages are used to calculate the relative atomic mass of an element.

The mass spectrometer was invented by the British scientist Francis Aston in 1919.

Periodic tables show an element's relative atomic mass (atomic weight) in the following format:



THE MOLE

Chemists need to know more than just the mass of tiny atoms. They often want to know the number of atoms that have participated in a chemical reaction or that are found in a given sample. Because atoms are so small, they cannot be counted the same way larger objects are counted. Instead, scientists use a number that allows them to associate the weight of a sample with the number of atoms it contains. The number chemists use is 6.0221415×10^{23}. This number, called Avogadro's number, is usually estimated at 6.02×10^{23}.

- **Mole**: a unit of measure used to express an amount of substance containing 6.02×10^{23} particles.
- A mole of an element contains 6.02×10^{23} atoms of that element. For example, a mole of carbon is made up of 6.02×10^{23} carbon atoms.
- The relative atomic mass of an element in grams always contains 6.02×10^{23} atoms.

EXAMPLE:

- **A mole of hydrogen—6.02×10^{23} hydrogen atoms —has a mass of 1.01 grams. Likewise, 1.01 gram of hydrogen contains 6.02×10^{23} atoms of hydrogen.**
- **A mole of carbon—6.02×10^{23} carbon atoms —has a mass of 12.01 grams. Likewise, 12.01 grams of carbon contain 6.02×10^{23} atoms because carbon is 12 times heavier than hydrogen.**

Quick Fact

Avogadro's number is HUGE. It is written out as 602,214,150,000,000,000,000,000, although we do not actually know the exact value of the numbers after the 5 (represented as zeros).

A mole (6.02×10^{23}) is similar to a dozen (12) because it describes the number of objects (or atoms, particles, or other) that are present in the sample. Think of a dozen apples and a dozen bowling balls – they will weigh different amounts even though there are 12 of each in a dozen. Likewise, a mole of carbon and a mole of hydrogen weigh different amounts because of their different atomic weights.

Think About It...

If you have a mole of people, how many people are there?

Have there ever been that many people on Earth —at one point in time or over the entire history of human life on Earth?

HISTORY: **AMEDEO AVOGADRO** (1776–1856)

Amedeo Avogadro was an Italian chemist known for his contributions to the theory of molarity and molecular weight. He also developed Avogadro's Law.

- **Avogadro's Law** states that for equal volumes of gases at the same temperature and pressure, the gases will have equal numbers of molecules.
- As a result, the relative molecular weights of any two gases are the same as the ratio of the densities of the two gases (under the same conditions of temperature and pressure).

The concept of a mole can be extended to compounds, molecules, and other larger substances.

EXAMPLE:

Suppose you want to figure out how many water molecules there are in a drop of water. A drop of water you can barely see might have a diameter of about 0.1 mm and a radius of 0.05 mm. We can use the formula for calculating the volume of a sphere to find the volume of the water droplet. The formula for the volume of a sphere is $^4/_3\pi r^3$, where r is the radius of the drop of water. The volume of a drop of water is:

$$\frac{4}{3}\pi\,(0.05\text{ mm})^3 = 0.0000005\text{ cm}^3 \rightarrow 5 \times 10^{-7}\text{ mL}$$

After finding the volume, we want to find the mass of the drop of water so that we can relate that value to the number of moles of water in a drop. We know that the density of water is 1 g/mL. Using the density formula, we know that the mass of the droplet is 5×10^{-7} g.

Finally, using the periodic table of atomic weights, we can see that 18 grams of water contain 6.02×10^{23} molecules of water. Water has a molar mass of 18 g/mol.

$$(5 \times 10^{-7}\text{ g}) / (18\text{ g/mol}) = 2.9 \times 10^{-8}\text{ mol}$$

That's very tiny! Use Avogadro's number to find the number of molecules (there are 6.02×10^{23} molecules in 1 mole):

$$(2.9 \times 10^{-8}\text{ mol}) \times (6.02 \times 10^{23}\text{ molecules/mol}) = 1.75 \times 10^{16}\text{ molecules}$$

We see that there are 1.75×10^{16} water molecules in that small drop of water. Written out, that's 17,500,000,000,000,000! It's no wonder scientists invented scientific notation!

Quick Facts

A **circle** is a 2-dimensional (2-D) shape in which all points on its edge are the same distance from its center. The **diameter** of a circle is the length of a straight line that touches two points along the edge and passes through the center. The **radius** is the distance from the center to any point on the edge. Therefore, as the example to the left shows, the radius of a circle is ½ the diameter.

If you divide the circumference (the distance around a circle) by its diameter, you will always get the same number. That number is pi (π), or approximately 3.142. Pi is also used to find the volume of a sphere.

A **sphere** is a perfectly round, 3-D object in which all points on its surface are the same distance from its center. Like a circle, the radius of a sphere is the distance from the center to any point on its surface.

CHEMICALS BY VOLUME—SOLUTIONS

A **solution** is a homogeneous mixture of one or more substances (solutes) dissolved in another substance (solvent). Ocean water, for example, is a massive solution made up of water, salts, and other substances.

Solutions consist of elements or compounds that are well mixed together. The particles of the solutes are mixed evenly with the particles of the solvent, making a solution look uniform throughout.

- **Solute:** the substance dissolved into the solution. The solute is usually the substance present in a lesser quantity and seems to disappear when fully mixed in.
- **Solvent:** the substance that the solute is dissolved in. The solvent is usually the substance present in a greater quantity.

EXAMPLE:

Dissolving salt into water creates a solution of salt water. Water is the solvent and salt is the solute.

- **Concentration:** the amount of solute in a solution. The concentration of a table salt solution indicates *how much* salt, NaCl, is present in the solution.
  - To concentrate (increase the concentration of) a solution, solute is added to the given volume of solvent. Alternatively, some of the solvent can be removed. A **concentrated solution** contains a large amount of solute, compared to the amount of solvent present.
  - By contrast, to dilute a solution, solvent is added or the amount of solute in a given volume is reduced. A **dilute solution** contains a small amount of solute, compared to the amount of solvent present.
  - Two common ways to express concentration are percent composition by mass and molarity.
    1. **Percent Composition by Mass (%):** the mass of the solute divided by the mass of the solution, multiplied by 100. (The mass of a solution is the mass of the solute *plus* the mass of the solvent.)

Quick Fact

What happens when you mix two solutions of the same substance with different concentrations in equal volumes? The concentration of the combined solution is the average of the two starting concentrations.

For example, if you mix equal volumes of a 20% solution of salt water with a 40% solution of salt water, the combined solution will be a 30% solution of salt water.

EXAMPLE:

The percent composition by mass of a 100 g solution of salt water that contains 20 g of salt is:

$$\frac{20\ g\ salt}{100\ g\ solution} \times 100 = 20\%\ solution$$

The percent composition by mass of a salt water solution with 40 g of water and 10 g of salt is:

$$\frac{10\ g\ salt}{50\ g\ total\ mass\ of\ solution} \times 100 = 20\%\ solution$$

2. **Molarity (M):** the number of moles of solute per liter of solution (which is not necessarily the same as the volume of the solvent).

EXAMPLE:

The molarity of a 4-liter solution containing 1 mole of salt is:

$$\frac{1 \text{ mol salt}}{4 \text{ L solution}} = 0.25 \text{ M solution}$$

Solvents have a limit to the amount of solute they can hold at a certain temperature. If solute is continually added to a solution, eventually the additional solute will no longer dissolve. This is known as the saturation point, which can change significantly with different environmental factors, such as temperature, pressure, and contamination.

- **Saturation:** the point at which additional solute can no longer be dissolved into a solvent.

  EXAMPLE:

  Fill a glass with room-temperature water. Add a teaspoon of table salt to the water and stir until it dissolves. Continue by adding one teaspoon of salt at a time and stirring the solution until the salt dissolves. At a certain point, is it no longer possible to dissolve the salt?

- **Supersaturated solution:** a solution that contains more dissolved solute than it can normally hold at a given temperature. It contains more dissolved solute than a saturated solution. A supersaturated solution is not stable, so eventually, the excess solute will precipitate out of the solution.

  A supersaturated solution is often formed by slowly cooling a saturated solution.

  EXAMPLE:

  Salt is added to a cup of water until the salt no longer dissolves. The solution is saturated, and excess salt rests at the bottom of the solution. To dissolve the excess salt, the solution is heated. At higher temperatures, water can hold more salt so the excess salt dissolves. However, this is a greater amount of salt than the water can normally hold at lower temperature. Therefore, as the solution cools, it is said to be supersaturated. A supersaturated solution of water and salt is not stable, so salt crystals will easily form out of the solution.

  – Crystals may form rapidly when the edge of the container is scratched or if a seed crystal is added.

Quick Fact

Typically as the temperature of a solvent increases, more solid solute can be dissolved in the solution. For example, a larger amount of sugar (sucrose) can be dissolved in hot water than in cold water.

Gases usually act in the opposite way. As a solvent gets warmer, it can dissolve *less* of a gaseous solute. For example, many gases, like oxygen gas, dissolve better in cold water than in hot water. As a result, certain fish must live in cold water in order to have enough oxygen and "breathe."

Solvents and solutes can be classified as either polar or nonpolar.

- **Polar solvents:** solvents made up of molecules with an uneven distribution of electrons, creating a partial negative and partial positive side. Polar solutes tend to dissolve in polar solvents.
  - Water, acetone, and acetic acid are polar solvents. Salts, sugars, and ammonia are polar solutes.
- **Nonpolar solvents:** solvents made up of molecules with an even distribution of electrons. There can be bonds in which electrons are shared unequally within the molecules, but they must balance one another out due to symmetry. Nonpolar solutes generally only dissolve in nonpolar solvents.
  - Oil and benzene are nonpolar solvents. Parrafin wax, hydrocarbons, and CO_2 are nonpolar solutes. (While CO_2 can dissolve in water, it is not readily soluble. Think about soda and how it "fizzes.")

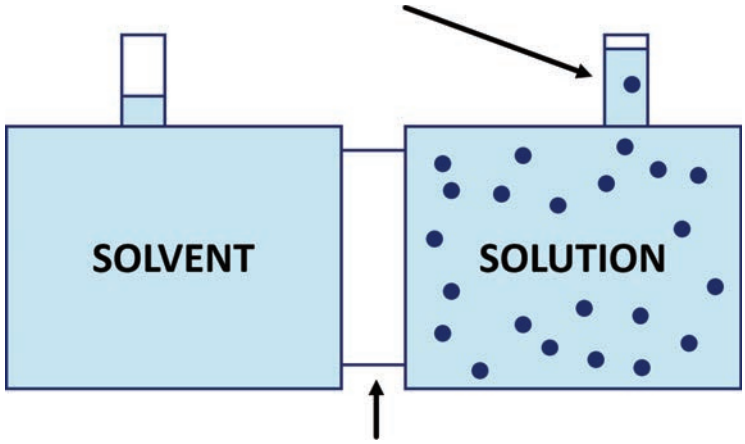
To figure out whether a solvent will dissolve a certain solute, remember that "like dissolves like." This means that the more alike two molecules are in terms of polarity, the more likely they are to mix.

NOTES

PHYSICAL PROPERTIES OF SOLUTIONS

Certain physical properties of solutions make them very useful to chemists. These properties depend on the number of solute particles as well as the identity of the solvent, but do not depend on the identity of the solute. Some examples of these properties are described in the table below:

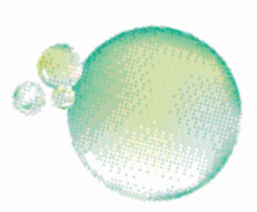
Physical Property of Solutions	Description of Property
Freezing point depression:	Solutions freeze at lower temperatures than the pure solvent. Antifreeze for automobiles freezes at a lower temperature than the pure solvent, water. (Antifreeze is a solution typically made of water and ethylene glycol.)
Boiling point elevation:	Solutions boil at higher temperatures than the pure solvent. Adding salt to water causes the solution to boil at a higher temperature. This decreases the amount of time it takes to cook food. This property of solutions is important at high elevations – without adding salt, water may boil at such a low temperature that food might not be cooked properly.
Osmotic pressure:	Certain membranes allow a solvent to pass through, but not the solute. When these membranes are used to separate a solution and additional pure solvent, more solvent flows into the side containing the solution. Eventually, enough additional solvent flows into the solution to build up enough pressure to stop the flow. Osmotic pressure due to the added solvent, shown by the added height of the liquid on the solution side.



Membrane allows the solvent (light blue background) to pass through, but not the solute particles (dark circles).

NOTES

SECTION IV:
ORGANIC CHEMISTRY



OBJECTIVES

- Define organic chemistry and identify organic compounds.
- Identify and describe hydrocarbons.
- Name organic compounds according to their structure.
- Explain hydrocarbon resources, such as coal and crude oil.
- Identify common chemicals in the human body and their functions.

Organic chemistry is the study of the structure, properties, and reactions of carbon-based compounds. Organic chemistry is everywhere – nearly everything contains something organic. Organic chemistry has been an important part of the development of medicines, foods, fuels, and many other chemicals used in everyday life. Over 90% of the millions of known compounds are organic compounds!

- **Organic compounds:** a class of chemical compounds that contain the element carbon. They often contain hydrogen, but may also contain many other elements, such as nitrogen or oxygen. They are usually held together by covalent bonds.
  - Organic compounds are often made by living things, but can also be synthesized in a lab.
  - The few carbon-containing compounds not classified as organic include carbon dioxide, carbides, carbonates, and cyanides.

C

CARBON

Atomic #6

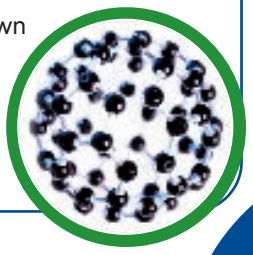
Carbon gets its name from the Latin word "carbo," meaning coal.

Characteristics of carbon:

- It is an essential building block for all organic compounds and forms more compounds than any other element.
- It is a main component of DNA, proteins, and carbohydrates.
- It is a main component of widely used fuels (coal, oil, and natural gas).

Elemental carbon is found in nature in four different solid forms:

- *Amorphous carbon*: found in charcoal and coal.
- *Graphite*: soft black layered form, used as a lubricant and in pencils.
- *Diamond*: crystalline form, one of the hardest known materials.
- *Buckminsterfullerene*: C_{60}, a sphere-shaped molecule, often called a "buckyball."



HISTORY: **ORGANIC CHEMISTRY**

"Organic chemistry" was named after the word "organism." During the early years of organic chemistry, all organic compounds were obtained from living organisms or the remains of those organisms. Prior to 1828, scientists believed that organic compounds could only be created in living matter, while inorganic compounds were created from non-living matter.

In 1828, however, German chemist Friedrich Wöhler accidentally synthesized urea (an organic substance found in the urine of most animals, including humans) from an inorganic compound. Wöhler's discovery changed the scope of organic chemistry to focus on the internal structure of atoms in matter.

- **Inorganic compounds:** a class of chemical compounds that do not tend to contain carbon and are produced either by natural processes or by humans in a laboratory.
  - They include minerals (such as salts and silicates), metals and their alloys (such as iron, copper, and brass), and pure water.

Quick Fact

The distinction between inorganic and organic compounds has become less important in recent years. This change is mainly the result of the discovery of new organic compounds. The majority of these new compounds have been synthesized in labs rather than coming from "natural" organic sources.

NAMING ORGANIC COMPOUNDS

Hydrocarbons are the simplest organic compounds. Hydrocarbons are made **only** of carbon (C) and hydrogen (H) atoms.

Carbon atoms bond to form rings and chains of many different shapes and sizes. A chain refers to two or more carbon atoms that are bonded together without forming a ring. For example, butane (on the next page) is a chain of 4 carbon atoms.

Three types of hydrocarbons are **alkanes**, **alkenes**, and **alkynes**. These types of hydrocarbons are named based on their types of chemical bonds and on the number of carbon and hydrogen atoms that they contain.

Alkanes: hydrocarbons that contain only **single** bonds.

- The name of each alkane begins with a specific prefix that indicates the number of carbon atoms present in that compound.
- The names of alkanes all end with "–ane."
- The general chemical formula for an alkane chain is C_nH_{2n+2}, where n is the number of carbon atoms.

EXAMPLE:

Methane (CH_4) is an alkane with only one carbon atom. Ethane is an alkane with two carbon atoms (n=2), so its chemical formula is $C_2H_{2(2)+2}$ or C_2H_6.

The table below lists the naming prefixes based on the number of carbon atoms:

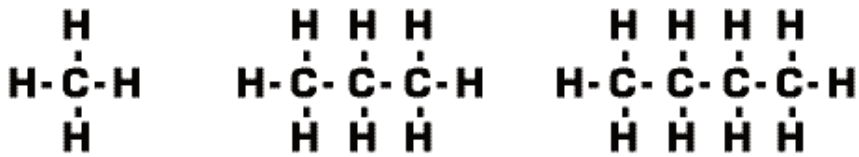
Number of Carbon Atoms	Prefix
1	meth-
2	eth-
3	prop-
4	but-
5	pent-
6	hex-
7	hept-
8	oct-
9	non-
10	dec-

Think About It...

Look at the structures of the alkanes below. Where does the general formula of an alkane, C_nH_{2n+2}, come from?

EXAMPLE:

The figures below show the structures of certain alkanes and their names. Notice that the prefix for the alkane matches the number of carbon (C) atoms in the figure.



methane (natural gas) **propane** **butane**

Alkenes: hydrocarbons that contain one or more **double** bonds between the carbon atoms in the molecule.

- At least two carbon atoms must be present in an alkene.
- To name an alkene, replace the "–ane" ending of an alkane with "–ene."
- The general chemical formula for an alkene chain with one double bond is C_nH_{2n}, where n is the number of carbon atoms.

Think About It...

As you read through this section, notice that each carbon atom always has four bonds. Its four valence electrons plus four electrons that it shares in covalent bonds give each carbon atom a full octet, making it stable. Look at each individual carbon atom in propane, for instance - each carbon has four bonds.

EXAMPLE:

Ethane ($CH_3 – CH_3$) becomes ethene ($CH_2 = CH_2$). Notice that the line between the molecules changes from a single line (single bond) in ethane to a double line (double bond) in ethene.

- If there are more than three carbon atoms in the hydrocarbon, each carbon atom gets a number. This number is used to identify the position of the double bond.
  - The carbon atom on the end closest to the double bond is given the number 1. The carbon atom next to carbon 1 gets the number 2. The numbering continues down the chain.

- To name an alkene, write the number of the carbon atom that is a part of the double bond and closest to the end of the chain first. This indicates the position of the double bond.
  - If the double bond is located at carbon 1, then this number does not have to be included in the name.
- The hydrocarbon chain is always numbered starting with the end that gives the double bond the *lowest* possible number.

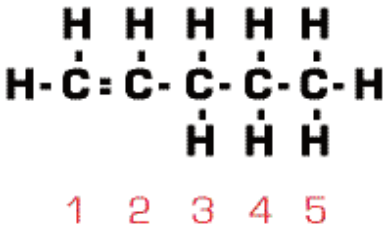
EXAMPLE:

The figures below show the structure of certain alkenes and their names. Notice that the number in front of the name matches the number of the carbon atom in the double bond that is closer to the end of the chain. The prefix for the alkene matches the number of carbon (C) atoms in the figure.

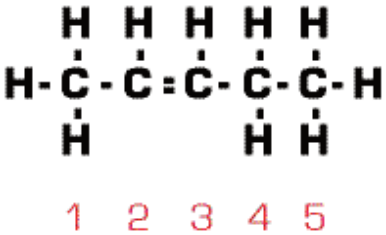
Remember that each carbon should have four bonds to be stable. The first carbon in pentene has 2 single bonds and 1 double bond for a total of four bonds.

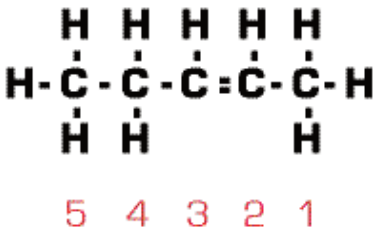
Think About It...

Look at the structures of the alkenes below. Where does the general formula of an alkene, C_nH_{2n}, come from?



1-pentene (or simply "pentene")

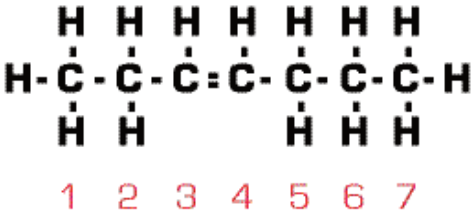




2-pentene

Notice that the two figures above have the same name.

They are the same structure but oriented in different ways.



3-heptene

Alkynes: hydrocarbons that contain one or more **triple** bonds.

- To name alkynes, replace the "–ane" ending of an alkane with "–yne."
- The general chemical formula for an alkyne chain with one triple bond is C_nH_{2n-2}, where n is the number of carbon atoms.

EXAMPLE:

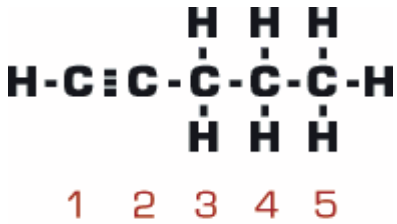
Ethane (CH_3 – CH_3) becomes ethyne (HC ≡ CH). Notice that the line between the molecules changes from a single line (single bond) in ethane to a triple line (triple bond) in ethyne.

Likewise, propyne is HC ≡ C–CH_3.

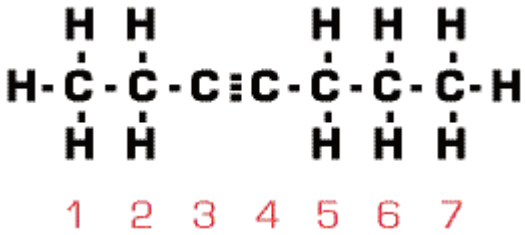
- Like alkenes, alkyne molecules that contain more than three carbon atoms have a number to indicate the position of the triple bond.
  - The carbon atoms are numbered in the direction that gives the carbon in the triple bond the lowest possible number.

EXAMPLE:

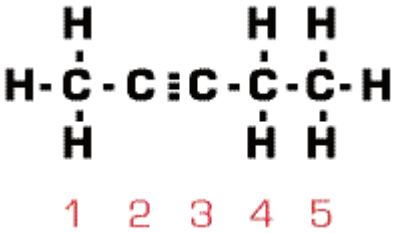
The figures below show the structures of certain alkynes and their names. Notice that the number in front of the name matches the number of the carbon atom in the triple bond that is closer to the end of the chain. The prefix for the alkyne matches the number of carbon atoms in the chain.

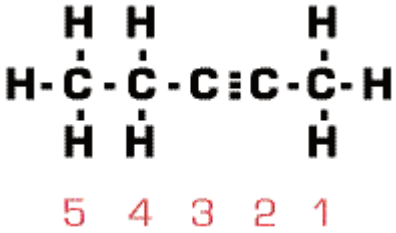


1-pentyne (or simply "pentyne")



3-heptyne





2-pentyne

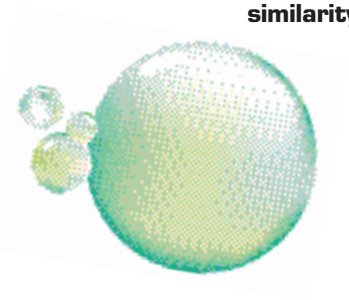
Notice that the two figures above have the same name.

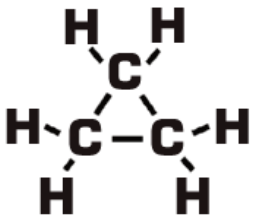
Cycloalkanes: hydrocarbons that contain singly bonded carbons in a ring.

- To name cycloalkanes, begin by taking the name of the alkane that has the same number of carbon atoms. Then add the prefix "cyclo–" to the name.
- Rings made up of only single bonds end with the "–ane" suffix.

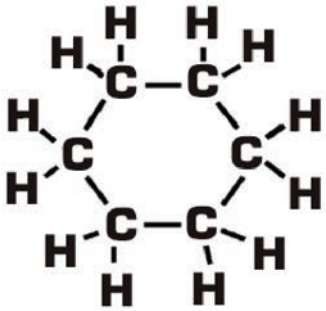
EXAMPLE:

The figures below show the structure of certain cycloalkanes and their names. Notice the similarity in naming between alkane chains and cycloalkane rings.





cyclopropane

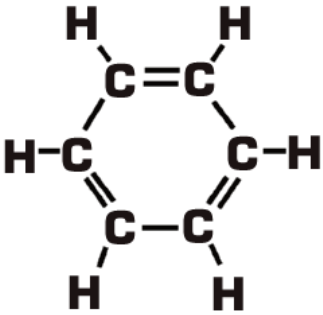


cyclohexane

Cycloalkenes and cycloalkynes also exist as compounds and are named similarly. One of the most common organic structures is benzene. Benzene is a hydrocarbon, even though it is an exception to the hydrocarbon naming rules. Its chemical formula is C_6H_6. Notice that benzene has a chemical formula different from cyclohexane (C_6H_{12}). Benzene contains double bonds, which makes it a very stable ring structure. Its stability is the reason that benzene exists naturally in many organic substances.

EXAMPLE:

Below is the Lewis structure of benzene. Notice the alternating double bonds in the ring.



benzene

Quick Fact

Benzene is used to make rubber, dyes, detergents, pharmaceuticals, explosives, and many other products. Benzene is also one of the most basic petrochemicals (see the section on Hydrocarbon Resources). However, many scientists refrain from using benzene due to its health hazards.

Quick Fact

Benzene actually does not have three discrete (separate) double bonds. The electrons in the double bonds are shared equally between all of the carbon atoms in benzene (see the structure on page 28).

SKELETAL STRUCTURES

Chemical compounds can be represented in many different ways. The previous section showed organic compounds using Lewis structures, but compounds can also be drawn using skeletal (or line-angle) structures. When drawing a skeletal structure, the following are important to know:

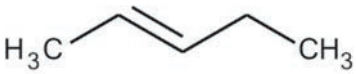
- The carbon and hydrogen atoms are not drawn out explicitly (shown completely) throughout the structure. Lone pair electrons are also not usually shown. Any element besides carbon or hydrogen must be shown.
- The peaks or corners within the structure represent carbon atoms.
- The ends of the chain represent carbon atoms, which are sometimes shown.
- The hydrogen atoms are not shown throughout the structure, but they are still there. They are attached to the carbon atoms (the peaks). Each carbon atom is bonded to however many hydrogen atoms are needed to give the atom four bonds total.
- The double and triple lines indicate that there is a double or triple bond in the compound.

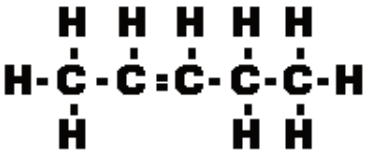
EXAMPLE:

To name the compound below, count the number of peaks (4) and add the carbons from each end (2). Sometimes the end carbons are drawn out (left), and sometimes they are implied (right). There are six total carbon atoms, so the name of the compound is hexane. The carbon atoms at each peak in chain below have single bonds with two other carbon atoms, so each must also be bonded to two hydrogen atoms to have four bonds total.

EXAMPLE:

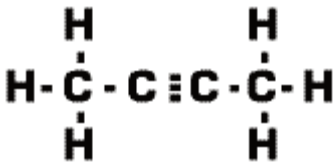
To name the compound below (left), count the number of peaks (3) and add the carbons from each end (2). There are five total carbon atoms. However, this time, notice that there is a double bond in the structure (shown by the short floating line), so the name of this compound is 2-pentene. Compare the skeletal structure to the Lewis structure.





EXAMPLE:

For the next structure, there are two peaks and two end carbons (4 total). This structure has a triple bond at carbon number 2 (shown by the short lines above and below the main structure), so the name of this compound is 2-butyne.



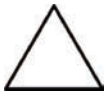
Quick Fact

Because of the orbitals used by carbon atoms to form triple bonds, carbons in triple bonds must be linear (or arranged in a straight line).

Just like carbon chains, cycloalkanes can be shown using skeletal structures. Again, for these structures, the peaks or corners represent carbon atoms.

EXAMPLE:

To name the compound below, count the peaks or corners (3). The name of this compound is cyclopropane. The carbon atoms at each peak corner below have single bonds with two other carbon atoms, so each must also be bonded to two hydrogen atoms to have four bonds total.



EXAMPLE:

To name the compound below, count the peaks or corners (6). The name of this compound is cyclohexane.

Quick Fact

Pure cyclohexane is very nonpolar. As a result, it is largely unreactive. Cyclohexane tends to only react with strong acids that force the ring to break.

EXAMPLE:

Remember, benzene has a structure similar to cyclohexane. It has six (6) corners, but it also contains double bonds (shown below by the floating alternating lines inside the structure).

Benzene is also often drawn with a circle in the middle to represent the alternating double bonds.

Quick Fact

Remember, the electrons in the double bonds are shared between all of the carbon atoms in benzene. The Lewis structure with a circle (at right) illustrates this more accurately than the Lewis structure with three alternating double bonds.

FUNCTIONAL GROUPS

Many organic compounds contain other elements in addition to carbon and hydrogen. These elements or groups of elements are called **functional groups**. A functional group is an atom or group of atoms in an organic molecule that usually reacts in a similar and specific way.

Functional groups influence the properties of compounds and how they react, so they are very helpful in studying organic chemistry because they can help predict what will happen in a reaction. For example, alcohols (molecules with an –OH group attached) like propanol and ethanol will react in similar ways.

Below are common functional groups, their general structures, and some examples. All of the examples are drawn using skeletal structures.

Alkyl Halides

An **alkyl halide** is an organic molecule containing a halogen and a carbon chain. Alkyl halides are part of a larger group known as **halocarbons** – any organic molecules containing a halogen substituent group.

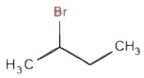
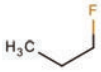
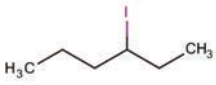
The general structural formula for an alkyl halide is:

R– X

R represents any carbon chain and X represents any halogen.

Follow these steps when naming alkyl halides:

1. Count the number of carbons in the longest carbon chain – this determines the name of the *parent chain* for that compound. The first example in the table below has four carbons, so the base name would be butane.
2. Determine what halide is attached to the parent chain and where. As with numbering carbons for compounds with double and triple bonds, start numbering at the end of the carbon chain that is closest to the functional group. In the first example below, the halide is bromine and it is attached at carbon two. Notice that if the numbering had begun with the right-most carbon, bromine would be at carbon three, which would be incorrect.
3. Place the number of where the halide is attached first, then add a dash (-).
4. Finally, add the prefix of the halide to the base name of the chain. The prefixes for the halogens found in alkyl halides are fluoro (F), chloro (Cl), bromo (Br), and iodo (I).

Compound	Compound Name
	2 - Bromobutane
	Fluoropropane*
	3 - Iodohexane

*Notice that when the functional group is attached to the first carbon, the number 1 in front of the name is not needed.

Alcohols

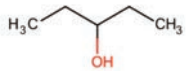
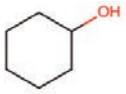
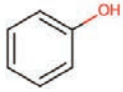
An **alcohol** is any organic molecule containing a hydroxyl group (–OH). The following is the structural formula for an alcohol, where R is a carbon atom or chain and OH is the hydroxyl group:

R– OH

The hydroxyl group can be attached to any carbon atom in the structure. Look at the table below, where the hydroxyl group is attached to a terminal (or ending) carbon, the middle of the carbon chain, and a carbon ring.

Naming alcohols is similar to naming halocarbons. However, instead of adding a prefix, the suffix –ol is added to a compound name. Follow these steps when naming an alcohol:

1. Determine the parent or main carbon chain.
2. Identify the carbon to which the hydroxyl group is attached. Add the number identifying the location of the hydroxyl group to the beginning of the name.
3. Finally, replace the final "e" in the parent chain ending (e.g., –ane) with the "–ol" ending.

Compound	Compound Name
	Butanol*
	3 - Pentanol
	Cyclohexanol*
	Phenol**

*Again, when the functional group is attached to the first carbon, the number 1 in front of the name is not needed. The number is also not for a hydroxyl attached to a carbon ring.

**Phenol is a special name for a benzene ring with a hydroxyl group directly attached. It is the common and IUPAC (International Union of Pure and Applied Chemistry) name.

Ethers

An **ether** is an organic compound that contains an oxygen atom bonded between two carbon atoms, either chains or rings. The basic formula for an ether is below, where R1 and R2 represent carbon rings or chains:

R1– O – R2

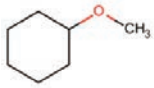
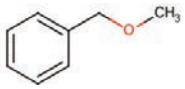
The IUPAC naming convention for ethers can be complex but there is also a simple way to name them. Use the following steps to name ethers:

1. Determine the two carbon chains attached to either side of the oxygen atom. For the first compound in the table on the next page, there is a butane group (4 carbons) on the left and an ethane group (2 carbons) on the right.

Quick Fact

Ether was first used as a name for ethyl ether. Ethyl ether is a flammable and volatile substance that was originally used in surgery.

2. Shorten the base names by removing the "–ane" ending and adding the "–yl" suffix to both names.
3. Place the two names together alphabetically.
4. Add "ether" to the end of the name.
5. If the two groups are the same, the compound can be named as a dialkyl ether, such as diethyl ether.

Compound	Compound Name
	Butyl ethyl ether
	Cyclohexyl methyl ether
	Benzyl methyl ether

Quick Fact

This is the simple way to name ethers. The IUPAC name can be long and confusing, so often scientists refer to ethers by their simple names. For example, butyl ethyl ether is the simple name, but the IUPAC name is actually ethoxybutane.

Aldehydes

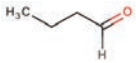
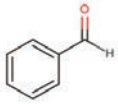
An **aldehyde** is a compound with a carbonyl group bonded at the end of a carbon chain. A carbonyl group is a carbon atom double bonded to an oxygen atom. In an aldehyde, the carbonyl group is bonded to a carbon atom on one side and a hydrogen atom on the other. The general formula for an aldehyde is below, where R represents carbon chains, carbon rings, or hydrogen:

When naming aldehydes, remember these steps:

1. Determine the parent chain, including the carbonyl carbon (the carbon double bonded to oxygen).
2. Replace the ending of the parent chain with "–al" when naming simple chains.
3. When naming ring structures, add "carbaldehyde" to the end of the parent chain and do not include the carbonyl carbon in the parent chain name.

Think About It...

Why doesn't the name of an aldehyde need to indicate where in the carbon chain the aldehyde is located? Where must an aldehyde be located on the chain?

Compound	Compound Name
	Butanal
	Cyclopentanecarbaldehyde
	Benzaldehyde*

*For benzene, you simply add "aldehyde" to the end of the parent chain instead of "carbaldehyde."

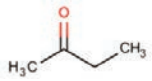
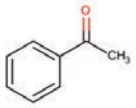
Ketones

A **ketone** is an organic molecule where the carbonyl group is bonded to two carbon atoms. The following is the formula for a ketone, where R1 and R2 represent carbon chains or rings:

$$R1-\overset{\overset{\displaystyle O}{\|}}{C}-R2$$

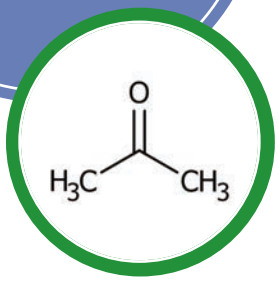
To name a ketone, use the following steps:

1. Determine the parent chain or structure, including the carbonyl carbon.
2. Identify the location of the carbonyl group by number.
3. Place the location number first and add the parent chain name.
4. Replace the "e" at the end of the parent chain with the suffix "–one."

Compound	Compound Name
	2 – Butanone
	Cyclopropanone
	Phenyl ethanone

Quick Fact

You have probably heard of acetone. Acetone (below) is a very common ketone often used as a solvent in organic reactions.



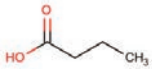
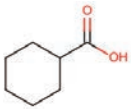
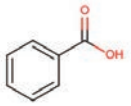
Carboxylic Acids

A **carboxylic acid** is an organic molecule that contains a carbonyl group bonded to a hydroxyl group. The following is the general formula for a carboxylic acid, where R represents a carbon chain, ring, or a hydrogen group:

$$R-\overset{\overset{\displaystyle O}{\|}}{C}-OH$$

Below are the steps for naming a carboxylic acid:

1. Determine the parent chain or structure, including the carbonyl carbon (except in ring structures).
2. Replace the "e" at the end of the parent chain with the suffix "–oic."
3. Add the word "acid" to the end of the name.

Compound	Compound Name
	Butanoic acid
	Cyclohexanoic acid
	Benzoic Acid

Think About It...

How does a carboxylic acid act as an acid in solution?

Esters

An **ester** is any organic compound in which the hydrogen of the hydroxyl group of a carboxylic acid is replaced by an alkyl group (or a carbon chain). The following is the basic structure for an ester, where R1 and R2 represent carbon chains or rings:

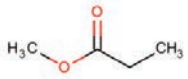
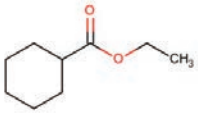
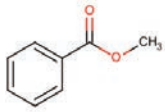
$$R1-O-\overset{\overset{\displaystyle O}{\|}}{C}-R2$$

Quick Fact

Esters generally have very nice smells. Esters are present in many flowers and fruits such as raspberries, oranges, and pineapples.

Follow these steps to name an ester:

1. Determine the name of the chain or structure bonded to the oxygen (not the carbonyl side). In the basic structure above, this is R1.
2. Shorten the base name by removing the "–ane" ending and adding the suffix "–yl." In the first compound below, the group is methane, and it becomes methyl.
3. Add the name of the other carbon chain, attached to the carbonyl, after the name of the first chain. Include the carbonyl carbon except in ring structures.
3. Replace the "e" ending of the second chain with the suffix "–oate."

Compound	Compound Name
	Methyl propanoate
	Ethyl cyclohexanoate
	Methyl benzoate

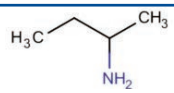
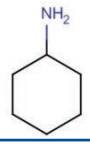
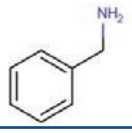
Amines

An **amine** contains a nitrogen atom bonded to carbon atoms in chains or rings. The general structural formula for an amine is below, where R is a carbon atom or chain:

$$R-NH_2$$

Naming amines:

1. Determine the parent chain. The first example in the table on the next page has four carbon atoms, so its parent chain is butane.
2. Find the carbon atom to which the amine is attached.
3. Add the number that identifies where the amine is attached.
4. Change the ending of the parent chain to "–ylamine."

Compound	Compound Name
	2 – Butylamine
	Cyclohexylamine
	Benzylamine

Think About It...

How many hydrogen atoms must be bonded to each of the carbons in cyclohexylamine?

Amides

An **amide** is an organic molecule where the –OH of a carboxylic acid is replaced by a nitrogen group. The general formula for an amide is below, where R1 and R2 represent carbon chains, rings, or hydrogen:

$$\mathbf{R1-\overset{\overset{\displaystyle O}{\|}}{C}-NH-R2}$$

The R2 group is bonded to nitrogen. The "H" written next to the nitrogen shows that nitrogen is also bonded to hydrogen, giving nitrogen a total of three bonds.

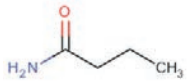
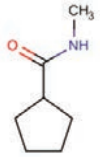
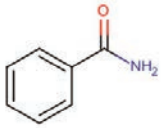
To name an amide where R2 is a hydrogen, such as the first and third compounds on the following page, follow these steps:

1. Determine the parent chain bonded on the carbonyl side (including the carbonyl carbon).
2. Replace the final "e" with "–amide."

To name an amide where R2 is a carbon chain, such as the second compound on the following page, follow these steps:

1. Determine the parent chain or structure bonded on the carbonyl side (including the carbonyl carbon).
2. Replace the final "e" with "–amide." (So far, this is the same whether R1 is a hydrogen or a carbon chain.)
3. Determine the other carbon chain attached to the functional group (R2 above). In the second example on the following page this is a methyl group.
4. Remove the "–ane" ending and add the suffix "–yl." Also add the prefix "N-," which indicates that the group is bonded to nitrogen.
2. Add the modified name of the R2 group in front of the name of the parent chain.

Note: In ring structures, add "–carboxamide" to the end of the parent chain instead of replacing the final "e." Benzene is an exception to this rule.

Compound	Compound Name
	Butanamide
	N-methylcyclopentanecarboxamide
	Benzamide

The table below summarizes the common functional groups, the names of compounds containing those functional groups, and their general structures. The R1 and R2 represent carbon chains with any number of carbons and hydrogens, such as $-CH_3$ or $-CH_2CH_3$. For example, methanol is $HO-CH_3$, where R1 is $-CH_3$.

Compound Type	General Formula	Functional Group
Alkene	**R– C = C – R2**	Hydrocarbon
Alkyne	**R– C ≡ C – R2**	Hydrocarbon
Halocarbon	**R– X**	Halogen
Alcohol	**R– OH**	Hydroxyl
Ether	**R1– O – R2**	Ether
Aldehyde	**O** ‖ **R– C – H**	Carbonyl
Ketone	**O** ‖ **R1– C – R2**	Carbonyl
Carboxylic Acid	**O** ‖ **R– C – OH**	Carboxyl (*carb*onyl and hydr*oxyl*)
Ester	**O** ‖ **R1– C – O – R2**	Ester
Amine	**R– NH_2**	Amino
Amide	**O** ‖ **R1– C – NH – R2**	Amide

HYDROCARBON RESOURCES

Hydrocarbons are often used as energy resources. **Fossil fuels** are fuels that contain hydrocarbons and are derived from the decomposed remains of living organisms. Fossil fuels are used to power homes, schools, cars, and more. Three major fossil fuels are coal, oil, and natural gas.

Coal: a black to brownish-black sedimentary rock.

- Coal contains carbon, hydrogen, and oxygen combined with smaller amounts of nitrogen and sulfur.
- Coal is formed from ancient plants and animals that lived hundreds of millions of years ago.
  - Different plants and animals died, decomposed, and were buried under layers of water and dirt millions of years ago.
  - The layers of dirt and rocks that built up over the trapped dead matter generated heat and pressure. The heat and pressure then converted the plant and animal remains into coal.
  - Because coal was formed by different organisms over different periods of time, several types of coal exist. The four types of coal found today are: anthracite, bituminous, subbituminous, and lignite.
- Coal is considered a nonrenewable energy source because it takes millions of years to create.
- Most of the coal used in the United States and worldwide is burned by electric power plants.
- Coal is rich in hydrocarbons. The simplest hydrocarbons, alkanes, are easily combusted and provide energy.
  - **Combustion:** an exothermic redox reaction between a substance (the fuel) and a gas (the oxidizer) that releases energy. Combustion is commonly called burning.
  - Combustion tends to occur in the presence of oxygen, but it can also take place in other gases.

EXAMPLE:

The general formula for the combustion of an alkane is illustrated in the reaction below:

Methane (alkane) + Oxygen → Carbon dioxide + Water + Energy

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

- Like methane, coal releases energy and water vapor when it is burned and provides power to generators, creating electricity.

Think About It...

What does the Lewis structure of methane look like? What about the Lewis structure of oxygen gas? Sketch them in the space to the left!

Crude oil: a mixture made mostly of hydrocarbon compounds.

- Crude oil can be found in many areas of the world. It has a major global influence both as a fuel source and in many industrial applications.
- Approximately 70% of crude oil is used to produce some type of fuel for transportation in the U.S.
- Crude oil is found underground as part of a formation called an oil reservoir.
  - Tiny droplets of crude oil are trapped in open spaces (pores) among rocks.
  - The layers of dirt and rocks that build up over the oil trap heat and pressure. The heat causes any gases trapped in the rocks to expand.
  - As a result, when an oil well strikes an oil reservoir, it releases the pressure. This release of pressure forces the crude oil up to the surface through the rocks.
  - After the majority of the natural pressure has been released, oil pumps are used to pump the crude oil to the surface.
- Crude oil has to be refined in order to be used. The components of the oil must be separated through a process called fractional distillation.
  - **Fractional distillation:** a method of separating a mixture into its parts based on their relative boiling points.
  - Most of the compounds found in crude oil are alkanes, so they have similar chemical properties.
  - Fractional distillation can separate the hydrocarbons using heat. Hydrocarbons with longer carbon chains have higher boiling points. Shorter carbon chains have lower boiling points.
  - The lower the boiling point, the higher up the fractionating column the hydrocarbons will travel. The higher the boiling point, the lower the hydrocarbons will rise up the fractionating column (see the image on the following page).

Quick Fact

Crude oil and natural gas are found in petroleum. Petroleum comes from the Greek word "petra" meaning "stone" and the Latin word "oleum" meaning oil. Petroleum means stone oil.

NOTES

FRACTIONAL DISTILLATION

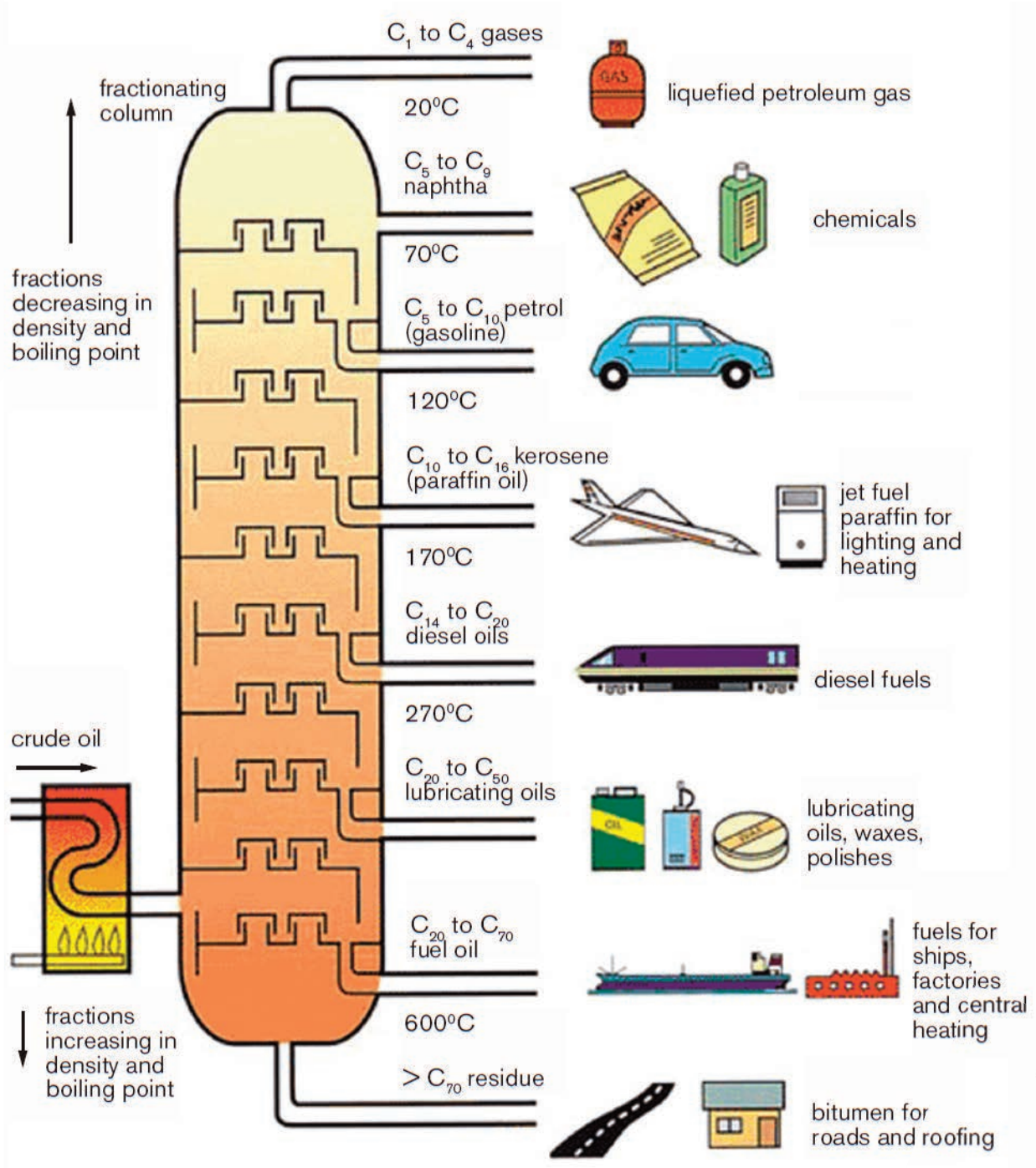


Image source: "Coryton Refining – Refinery Processes." *The Institute of Petroleum*. Energy Institute. September 16, 2008

The subscript after C indicates the number of carbons in the hydrocarbon chain. C_5, for example, could represent pentane, C_5H_{12}; cyclopentane, C_5H_{10}; or another hydrocarbon containing five carbons.

CHEMISTRY IN THE HUMAN BODY

The human body is composed of various chemical compounds, including water and many organic compounds. Organic compounds in the human body have varying roles and are essential to development, growth, and survival. These organic compounds include proteins, carbohydrates, lipids, nucleic acids, and vitamins.

Quick Fact

About 60% of an adult human's body is made of water. Newborn babies are about 75–78% water. By the time a baby reaches one year old, the percentage of water in the body has dropped to about 65%.

PROTEINS

Proteins are complex organic compounds consisting of carbon, oxygen, hydrogen, nitrogen, and occasionally sulfur. Proteins are involved in almost all cell functions and help the body to grow and to repair damage.

- Proteins are found in body organs, muscles, ligaments, skin, and hair.
- Some proteins provide structural support, while some are involved in body movement, and others protect the body from germs.
- Proteins in the body include:
  - Many *hormones*, like insulin, which help to regulate body functions.
  - *Enzymes*, which catalyze chemical reactions in the body. The amino acids that make up an enzyme form a long chain that folds into a unique shape (see the information on amino acids below). The unique shape allows the enzyme to facilitate specific chemical reactions so they occur very quickly.
- The body uses protein to make hemoglobin. **Hemoglobin** is a component of red blood cells which carries oxygen through the body.
- Proteins are made of long chains of molecules called amino acids, so they are classified as polymers (see the section on Polymers).
- **Amino acids:** substances that make up proteins. They are the building blocks of proteins.
  - There are only about 20 naturally occurring amino acids. However, they bond together in different combinations to create the millions of proteins found in living organisms.
  - The body can make most, but not all, of the amino acids it needs to create proteins.
    - The nine amino acids that the human body cannot make are called **essential amino acids**. These amino acids must be obtained from food sources.
    - Both plant and animal foods contain protein. Animal products, such as meat, fish, poultry, dairy, and eggs, are considered *high quality* proteins or *complete proteins* because they contain the essential amino acids.

Quick Fact

The nine essential amino acids include phenylalanine, tryptophan, isoleucine, leucine, valine, methionine, lysine, and threonine. Histidine is also categorized as an essential amino acid, but because studies have shown that the dietary requirements for histidine are very low, some sources exclude histidine and refer to only eight essential amino acids.

CARBOHYDRATES

Carbohydrates are the most abundant group of organic compounds found in living organisms. These chemicals are broken down during chemical processes known as *metabolism* to generate energy. They serve as the main source of energy in the human body.

All carbohydrates are made up of sugars (or saccharides).

- **Monosaccharides:** simple sugars that cannot be broken down into smaller sugars. They are the most basic form of carbohydrates.
  - Monosaccharides result from the digestion of more complex carbohydrates.
  - They are small enough to be absorbed through the walls of the digestive system and transported into the blood.
  - Most monosaccharides are either:
    - *Hexoses* (sugars containing 6 carbons) like glucose, galactose, and fructose.
    - *Pentoses* (sugars containing 5 carbons) like ribose and deoxyribose.
  - Glucose, galactose, and fructose are known as *structural isomers* because they have the same chemical formula ($C_6H_{12}O_6$), but their atoms are arranged in different orders.
  - Ribose and deoxyribose sugars are important in the formation of the nucleic acids, DNA and RNA.
- **Disaccharides:** sugars composed of two monosaccharides.
  - Lactose (milk sugar) is a disaccharide made from one molecule of glucose and one molecule of galactose.
  - Sucrose (cane sugar) is commonly used in baking. It is made from one molecule of glucose and one molecule of fructose.
  - Maltose (malt sugar) is made of two molecules of glucose and is formed from the digestion of starch.
- **Polysaccharides:** relatively complex carbohydrates composed of many monosaccharide units joined together.
  - They are polymers and can have a linear or branched structure.
  - Most natural carbohydrates occur in the polysaccharide form.
  - The polysaccharide *starch* is a naturally abundant nutrient carbohydrate. It is found in corn, potatoes, wheat, and rice.

Quick Fact

The monosaccharide glucose passes in and out of cells where it is used for energy purposes. Abnormal levels of this chemical in the blood can be associated with the disease diabetes.

Quick Fact

The names for most sugar compounds end in the letters "–ose."

Quick Fact

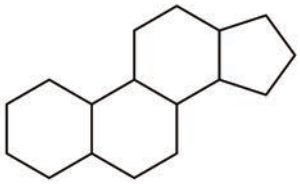
Chitin ($C_8H_{13}O_5N$) is a polysaccharide found in the exoskeletons of crustaceans, spiders, and insects.

LIPIDS

Lipids are a group of organic compounds that are insoluble in water. They play an important role in insulation (reducing the rate of heat transfer to keep the body warm) and regulation of body functions.

Lipids are often referred to as fats, but fats are only one type of lipid.

- **Triglycerides (fats and oils):** organic compounds that are part of the lipid family. They are produced by a reaction between glycerol (a type of alcohol) and three fatty acids.
  - Triglycerides have structural and metabolic functions in the human body. They are said to be the body's energy reserve because excess fat is stored in the body and metabolized for energy when needed. For example, the body metabolizes fats during low-intensity exercise or when food is not available.
  - Fats tend to be solid at room temperature. Oils tend to be liquid at room temperature.
  - Triglycerides are also an important part of the human diet. Edible fats include butter and margarine. Edible oils include peanut oil and olive oil.
- **Steroids:** important biologically active compounds in the lipid family. They have a basic structure of three 6-membered rings and one 5-membered ring (as shown in the image below).



  - The most common steroid is cholesterol.
  - **Cholesterol:** a major component of cell membranes produced in a variety of body tissues, such as the liver. It is also obtained through food.
    - In the human body, cholesterol is concentrated in the brain and spinal cord.
    - Cholesterol is necessary for the production of vitamin D, bile acid (for digestion), estrogen, and testosterone.

Quick Fact

There are two types of cholesterol: low-density lipoprotein (LDL) and high-density lipoprotein (HDL) cholesterol. LDL is considered "bad" cholesterol because it can slowly build up on artery walls and lead to a heart attack or stroke. HDL is considered "good" cholesterol because high levels of this type seem to prevent heart attacks.

NUCLEIC ACIDS

Nucleic acids are large molecules that carry genetic information and direct cellular functions. The two types of nucleic acids are deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).

- **DNA:** a nucleic acid that contains the genetic instructions for the biological development of all cellular life forms (and most viruses).
  - DNA has a double helix structure made up of two "polynucleotide" chains.
  - Each chain has a sugar-phosphate backbone with a series of bases attached.
  - The four different bases present in DNA are adenine, thymine, cytosine, and guanine.

- **RNA:** a nucleic acid that transmits genetic information within a cell from DNA to the ribosome, where the information is used to synthesize proteins.
  - RNA is generally a single-stranded chain of nucleotides.
  - Like DNA, RNA contains the bases adenine, cytosine, and guanine. However, instead of thymine, RNA's fourth nucleotide is the base uracil.

VITAMINS

Vitamins are fat-soluble or water-soluble organic substances that are essential for the growth and development of the human body. Vitamins cannot be produced in the body in large enough quantities, so they must be obtained from plant and animal foods.

Examples of common vitamins and their characteristics are listed in the table below:

Vitamin	Characteristics/Functions
Vitamin B	• The B vitamins are eight water-soluble vitamins. They are critical for metabolic reactions in the body and for fighting infections. • The B vitamins include B1 (thiamine), B2 (riboflavin), and B3 (niacin). • The B vitamins often work together to deliver health benefits to the body. For example, they promote cell growth and enhance the function of the immune and nervous systems.
Vitamin C (L-ascorbic acid)	• The majority of plants and animals are able to synthesize their own vitamin C. Humans cannot synthesize vitamin C, so they must obtain the vitamin through their diet. • Vitamin C is commonly found in fresh fruits and vegetables. • Lack of vitamin C in the diet may cause scurvy, a disease characterized by extreme weakness and bleeding under the skin.
Vitamin D	• Vitamin D is a fat-soluble vitamin found mostly in milk, milk products, green leafy vegetables, seeds, and nuts. • Vitamin D is important for the development of bone tissue. • In humans, vitamin D_3 is produced by skin exposed to sunlight, specifically UVB radiation (see section Types of Electromagnetic Radiation).

HISTORY: **DOROTHY HODGKIN** (1910–1994)

Dorothy Crowfoot Hodgkin used X-ray crystallography to determine the structures of penicillin, vitamin B12, and insulin. Her research has allowed scientists to develop treatments for diseases and deficiencies, such as anemia and diabetes. In 1964, Hodgkin won the Nobel Prize in chemistry, becoming only the third woman to receive that honor.

SECTION V:
APPLICATIONS OF CHEMISTRY IN EVERYDAY LIFE

OBJECTIVES

- Describe chemical processes that are used to make particular foods.
- Identify common chemicals found in your home.
- Identify common chemicals found in automobiles.
- Distinguish between gasoline and diesel fuel.

CHEMISTRY IN YOUR KITCHEN

Although you may not think of chemistry when you think of food, chemical reactions play an important role in what you eat. Chemical reactions are involved in making and preparing many food products.

Quick Fact

An entire field of chemistry is devoted to food. Food chemists:

- Develop and improve food and beverage products
- Analyze methods for cooking, storing, and packaging food
- Study the effects of processing on the appearance, taste, aroma, freshness, and vitamin content of food
- Modify foods to control nutrient and calorie content

FERMENTATION

Fermentation is an important food process in which microorganisms are grown on a sugar-based medium. During fermentation, sugar is converted to an acid or an alcohol. A common form of fermentation is called alcohol fermentation. It converts glucose into ethanol and carbon dioxide gas:

$$C_6H_{12}O_6\ (aq) \xrightarrow{\text{yeast}} 2CO_2\ (g) + 2C_2H_5OH\ (aq)$$

- Many fermentation reactions are catalyzed by a group of enzymes that come from yeast, a type of fungus. The word "yeast" written above the arrow in the chemical equation signifies that yeast acts a catalyst in the reaction.
- Fermentation processes include:
  - The bacterial fermentation of milk, to make cheese and yogurt.
  - The conversion of sugar to alcohol, to make beer and wine.
  - The baking of bread. When baking, fermentation produces bubbles of CO_2 that cause the dough to rise.

Quick Fact

Yeast is actually alive! Yeast is a type of organism called a fungus. The catalyst is technically an enzyme found in yeast, and not the yeast itself.

COMMON CHEMICALS IN YOUR KITCHEN

The table below lists the chemical names and formulas of some common kitchen items:

Common Name	Chemical Name	Chemical Formula	Function/Use
Baking soda	Sodium bicarbonate	$NaHCO_3$	cooking/baking ingredient and odor reducer
Carbonated water (seltzer water)	Carbonic acid	$H_2CO_3(aq)$	soft drink ingredient
Rock salt (table salt)	Sodium chloride	NaCl	seasoning
Table sugar (cane sugar)	Sucrose	$C_{12}H_{22}O_{11}$	sweetener

Quick Fact

You may have heard people refer to vinegar as acetic acid (CH_3COOH). However, vinegar is not purely acetic acid. It is actually a very diluted solution of acetic acid. Household vinegar, used in cooking, generally only contains between 4% and 8% acetic acid.

SUGAR

Sugars are water-soluble carbohydrates (see the section on Chemistry in the Human Body).

- Most sugars have the general molecular formula $C_n(H_2O)_m$ with n and m each representing some number.
- Sugar molecules have many hydroxyl (–OH) groups, which can form hydrogen bonds with each other and with water.
- Sugars are solids at room temperature and are very soluble in water.
- Sugars such as glucose, fructose, and sucrose are commonly used as sweeteners in food and drinks.
- Several synthetic sugar substitutes have been developed. These substitutes include saccharin, aspartame (NutraSweet®), and sucralose (Splenda®).
  - These artificial sugars have lower calories per gram than regular sugar.
  - Artificial sweeteners also provide more sweetness per gram than regular sugar. The same volume of an artificially-sweetened drink will end up weighing less than a sugar-sweetened drink.

Fehling's and Benedict's solutions are used to test for sugars.

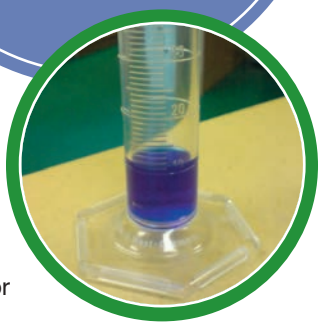
- **Fehling's solution:** a liquid substance made up of two separate solutions that are combined just before using to test for sugars.
  - Fehling's solution A is aqueous copper sulfate. Fehling's solution B contains sodium hydroxide and potassium sodium tartrate.
  - The two solutions are combined just before use because the combined, deep-blue alkaline solution will oxidize quickly.

- When Fehling's solution is heated with a substance containing a simple sugar, a dark red precipitate will form.

- **Benedict's solution:** a blue alkaline solution that is mainly made up of copper sulfate, sodium citrate, and sodium carbonate.
  - Like Fehling's solution, Benedict's solution forms a precipitate in the presence of simple sugars.
  - The precipitates are likely to be very small, but Benedict's solution also changes color to green, yellow, and brick red to indicate the amount of sugar in the solution. Green indicates that very little sugar is present. Dark red indicates a high concentration of sugar.
  - Benedict's solution is often used in place of Fehling's solution today because it allows for some quantitative analysis.

Quick Fact

Fehling's and Benedict's solutions can be used to test for glucose in urine. These tests can help to detect diabetes.



The simple sugar glucose is produced by plants through photosynthesis. Both plants and animals need glucose for energy. Glucose that is not needed right away is stored for later use.

Most plants store glucose in the form of either cellulose or starch. Most animals store glucose in the form of glycogen.

Starch: a polymer consisting of many glucose units (see the section on Polymers).

- Starch is formed by plants to store excess glucose.
- Starch occurs in two forms:
  - Alpha-amylose (or simply amylose), in which the glucose units are linked together in straight chains.
  - Amylopectin, in which the chains are branched.
  - Natural starches are mixtures of amylopectin and alpha-amylose. For example, wheat is made up of about 75–80% amylopectin and 20–25% amylose.
- In the digestive tracts of mammals, starch chains are broken down into individual glucose units by the enzyme *amylase*.

Quick Fact

Iodine can be used to test for starch. The iodine molecule reacts with the starch to form a compound with a dark blue or black color. If starch is not present, the color of the test solution will remain orange or yellow.

Cellulose and disaccharides, like sucrose, will not change color when exposed to the test solution.

I

IODINE

Atomic #53

Iodine is a halogen that gets its name from the Greek word "iodes," meaning "violet."

Characteristics:

- Is a bluish-black, shiny solid.
- Changes at ordinary room temperatures into a blue-violet gas with a strong odor.
- Is used in solution as a disinfectant for cuts and wounds.
- Is an essential element for human life that is needed for cellular metabolism and normal thyroid function.
- Is often added to table salt (iodized salt) to provide the minimum iodine requirements for good health.

Cellulose: a polymer, like amylose starch, that consists of linear chains of glucose molecules. In cellulose, however, the bonds between the glucose units have a different arrangement than in starch.

- Mammals are unable to digest cellulose without the help of certain enzymes.
- Some mammals, such as cows and deer, are able to survive on cellulose. These mammals are able to digest cellulose becaue their digestive tracts contain bacteria that produce *cellulase* enzymes. The cellulase enzymes works to break down the cellulose.

Quick Fact

Cotton is a pure, natural form of cellulose. Wood pulp and many supporting plant structures, like leaves, contain cellulose.

Glycogen: an organic polymer with a branched structure that resembles starch because it consists of chains of glucose units.

- Glycogen is formed and stored mainly in the liver and muscles.

Quick Fact

Just as most sugar names end in "–ose," the names of the enzymes that catalyze reactions of the sugars end in "–ase."

PEPPER

Pepper is often used as a seasoning and affects the flavor of food through chemical reactions that occur with the receptors on your tongue. Two kinds of peppers commonly used to season foods are black pepper and chili (or red) pepper.

Black pepper comes from the berry or "peppercorn" of the climbing plant *Piper nigrum.*

- When the peppercorn berries first begin to ripen, they are picked and dried to make black pepper.
- Black pepper has a spicy flavor that comes from the chemical compound piperine ($C_{17}H_{19}NO_3$).

Red pepper comes from the family of plants known as Capsicum.

- Red peppers include bell peppers, paprika, cayenne, tabasco, and habanero peppers.

- Red peppers derive their "heat" from a chemical known as capsaicin ($C_{18}H_{27}NO_3$).
  - Capsaicins bind with pain sensors in the mouth, releasing pain transmitters that travel to the brain. The brain senses the pain as "heat" and even signals the body to increase perspiration (sweating).
  - Capsaicins are nonpolar and are not soluble in water, so drinking water after eating a hot pepper does not help a great deal. Something with some acidity, like tomato or orange juice, will more effectively neutralize the alkaline capsaicin. Yogurt or milk may also be effective, since they contain fats that can help dissolve the capsaicin.

Quick Fact

The "heat" of peppers is measured in Scoville Heat Units (SHU).

- Bell peppers measure 0 SHU.
- Jalapeños measure about 5,000 SHU.
- Habaneros measure about 300,000 SHU.
- Pure capsaicin measures about 16,000,000 SHU.

The pepper spray carried by law enforcement officers is about 5,000,000 SHU.

GARLIC

Garlic is an herb that contains hundreds of chemical compounds. Many of those compounds contain sulfur, which contribute to its strong smell and flavor.

One major compound in uncooked garlic is a chemical called allicin ($C_6H_{10}OS_2$). Garlic releases this chemical when it is crushed or cut. It has antimicrobial properties and acts as a defense mechanism against other organisms. Allicin may even cause a burning sensation.

So how can we eat garlic without experiencing this uncomfortable sensation? Allicin is an unstable compound, which means it converts into other compounds. When the garlic is roasted, heated, or left out for a period of time, the allicin changes into a different sulfur compound. This allows us to enjoy garlic without an uncomfortable sensation.

CAFFEINE

Caffeine ($C_8H_{10}N_4O_2$) is naturally produced in the seeds, leaves, and fruits of many plants. Coffee beans and tea leaves are well known for their caffeine content. Caffeine is believed to act as a natural pesticide. It can paralyze and kill insects that try to feed on plants.

- When purified, caffeine is an intensely bitter white powder.
- In humans, caffeine stimulates the central nervous system, heart rate, and respiration process. It also acts as a mild diuretic (a diuretic is a substance that increases the rate of urine production).
- Caffeine is what gives coffee and tea their "wake up" boost and slightly bitter flavor. It is also added to colas and other soft drinks as a flavoring ingredient.

CHOCOLATE

A relative of the caffeine molecule called **theobromine** ($C_7H_8N_4O_2$) is the key ingredient in chocolate. Caffeine and theobromine have similar chemical structures.

- Theobromine comes from the beans of the cacao tree (or cocoa tree).
- Theobromine has similar effects on humans as caffeine, but the effects of theobromine are weaker. Theobromine acts as a mild stimulant but has little effect on the central nervous system.
- Different types of chocolate contain different amounts of theobromine.
  - "Milk" chocolates contain about 45–60 milligrams of theobromine in every ounce of chocolate.
  - "Dark" sweetened chocolates and "semisweet" chocolates usually contain about 150–160 milligrams of theobromine in every ounce of chocolate.
  - Pure cocoa beans are extremely rich in theobromine. Dry cocoa powder contains approximately 800 milligrams of theobromine in every ounce.

Quick Fact

Cocoa and chocolate products may be lethal to dogs and other domestic animals like horses. These animals metabolize theobromine more slowly than humans.

NOTES

CHEMISTRY IN YOUR AUTOMOBILE

Cars, trucks, buses, and other vehicles help us to get around every day. These vehicles need chemistry to function every step of the way.

GASOLINE

Gasoline is a mixture of hydrocarbons used mainly as a fuel for automobiles.

- Gasoline is made from crude oil, which contains hydrocarbons (see the section on Hydrocarbon Resources).
  - The carbon atoms in crude oil link together to form chains of different lengths. These different chain lengths can be separated from each other and mixed together to make different fuels.
  - Chains with 5–10 carbons (generally molecular chains from C_7H_{16} through $C_{10}H_{22}$) are processed and blended together to make gasoline.

Some cars use internal combustion engines. An internal combustion engine compresses a cylinder full of air and gasoline vapor. The mixture of compressed air and gasoline is then ignited (set on fire) by a spark from a spark plug.

Quick Fact

The hydrocarbon chain molecules that make up gasoline all vaporize at temperatures below the boiling point of water. If you spill gasoline outside, it will evaporate quickly.

Gasoline is given an **octane rating**, which indicates how much the gasoline can be compressed before it ignites on its own.

- Gasoline that ignites from compression only (instead of from a spark) can cause damage to a car's engine.
- Heptane ignites easily on its own when compressed. Octane can handle much more compression before it ignites.
- Standard "regular" gasoline is 87-octane.
  - This means that the gasoline contains 87% octane and 13% heptane. This number is based on a ratio, so this is a mixture that is 87 parts octane and 13 parts heptane.
  - Lower-octane gasoline, such as "regular" gasoline, ignites with the least amount of compression.
  - "High-performance cars" with "high-performance engines" need higher-octane fuel that can handle a greater amount of compression.

Quick Fact

Before filling stations (gas stations) were built, Americans bought gasoline in cans to fill their gas tanks.

DIESEL

Most tractor-trailers and other large trucks use diesel fuel because it tends to be more fuel efficient.

Diesel or diesel fuel is also a mixture of hydrocarbons that come from crude oil.

- The hydrocarbon chains that make up diesel fuels contain between 14 and 20 carbons, including cetane ($C_{16}H_{34}$).

The fuel cylinder in a diesel fuel engine is ignited solely by compression instead of a spark. A diesel engine is an internal combustion engine. The heat from the highly compressed air in the cylinder causes the fuel to ignite.

Similar to the octane rating of gasoline, diesel fuels are given a cetane rating. A **cetane number (cetane rating)** is a measure of the combustion (ignition) quality of diesel fuel. It is based on the percentage of cetane in the fuel.

- The cetane number actually measures the fuel's ignition delay. It measures the time period between when the engine is started and when the fuel is ignited.
  - Higher cetane fuels have a shorter ignition delay than lower cetane fuels.
  - "Regular" diesel fuel generally has a cetane number between 40 and 45. "Premium" diesel fuel generally has a cetane number between 45 and 50.
  - More efficient diesel fuels have a higher cetane number, which also means greater fuel efficiency.

Diesel fuel tends to be more fuel-efficient (burning less fuel in the same distance) than gasoline. However, burning diesel fuel cleanly is more difficult.

- Diesel fuels typically contain higher quantities of sulfur, which can be harmful to the environment.
- In recent years, diesel vehicles have become much cleaner. A new type of diesel fuel, called ultra-low sulfur diesel (ULSD), is required for new diesel vehicles.

ANTIFREEZE

The engines of cars and trucks produce a lot of heat. Too much heat within the engine of a car can cause damage, so some of the heat must be removed to protect the car and prevent overheating.

Antifreeze is a chemical that is mixed with water and added to the cooling system of a car.

- The most common chemical used in antifreeze is ethylene glycol ($C_2H_6O_2$).
- The antifreeze-water mixture moves through an automobile engine to remove extra heat.
- Antifreeze gets its name from the fact that it has a lower freezing point than water. The lower freezing point prevents the engine coolant from freezing in cold temperatures.
- Antifreeze also has a higher boiling point than pure water. This property makes it useful in hot temperatures as well.

Think About It...

How many valence electrons are in one molecule of ethylene glycol? What could its Lewis structure look like?

BATTERY ACID

Not only do automobiles use gasoline, they also use a battery. A car battery is a type of rechargeable, lead-acid battery that supplies electric energy. A car battery gives power to the lights, radio, and ignition system of an automobile.

The acid contained in lead-acid car batteries is commonly called battery acid.

- **Battery acid:** diluted sulfuric acid used in storage batteries that help power motor vehicles.
  - Battery acid is a mixture of about 33–35% sulfuric acid (H_2SO_4) and water.
  - Although battery acid is diluted sulfuric acid, it is still very corrosive. It can cause severe damage to human skin. This is why wearing protective gloves and safety glasses is necessary when changing a car battery.

S

SULFUR

Atomic #16

Sulfur is found near hot springs and volcanoes.

Characteristics:

- Is a pale yellow, brittle solid.
- Is an essential element for life because it is a component of hair, muscle tissues, and the hormone insulin.

Most of the world's sulfur production is used to make sulfuric acid (H_2SO_4). Sulfuric acid is used in lead-acid car batteries, fertilizers, the bleaching of paper, and many other industrial processes.

Sulfur dioxide (SO_2) is especially toxic to simpler organisms, such as fungi. For this reason, it is used for sterilizing dried fruit and wine barrels.

Most sulfur compounds have foul odors, smelling like rotten eggs or skunk spray.

NOTES

SECTION VI:
INDUSTRIAL APPLICATIONS OF CHEMISTRY

OBJECTIVES

- Identify common alloys.
- Define monomers and polymers.
- Describe methods for synthesizing polymers.
- Identify different types of plastics and their uses.
- Describe biopolymers and identify biopolymers in the human body.
- Explain the process of making rubber and the use of sulfur in that process.
- Define pharmaceuticals and identify different ways to classify them.

ALLOYS

Multiple metal elements are often mixed together to enhance the properties of the resulting metal. **Alloys** are homogeneous mixtures made of two or more metal elements or of a metal and a nonmetal.

- Changing the makeup of an alloy may change properties such as its density, hardness, conductivity, melting point, and malleability (see the section on Intramolecular Forces from *Chemistry Connections*).
- Alloys are also created to prevent corrosion, which is the oxidation of a metal, usually in the presence of moist air. The rusting of iron is an example of corrosion.
- Some common alloys include:
  - *Alnico* is made of iron, aluminum, nickel, and cobalt. It is used to make strong permanent magnets.
  - *Brass* is made of copper and zinc. It has a gold color and does not corrode. The color of brass depends on the amount of zinc in the alloy; the more zinc it contains, the lighter its color. Brass is harder than both copper and zinc.
  - *Bronze* is made mainly of copper and tin. It has good hardness and corrosion resistance. Bronze has been used for over 3,000 years to make statues, weapons, and household materials. Today, bronze is often used to make machine parts, such as gears, because it creates very little friction.
  - *Pewter* is made of tin, copper, bismuth, and antimony. It is a malleable metal used to make tableware, like cups and dishes, and other decorative items. The main component of pewter is tin. Modern pewter is at least 90% tin. In Roman times, the only other component in pewter was lead. Today, copper, bismuth, and antimony are usually used instead of lead.
  - *Steel* is made of iron and carbon. It is a strong metal often used in construction. *Stainless steel* contains chromium and/or nickel and is resistant to rusting.
  - *White gold* is generally made of gold and nickel or palladium. It became popular in the 1920s for making "white" jewelry. It was used as a substitute for platinum, which was much more expensive.

POLYMERS

Polymers are long, chain-like molecules formed by connecting many repeating units, called monomer units. Water bottles, tires, contact lenses, and DNA are all composed of polymers. Some common polymers include:

- *Polyester*, which is used for wrinkle-free fabric.
- *Polyurethane*, which is used to make flexible foam for bedding and upholstery and rigid foam for wall panels and refrigerators.
- *Polymethylmethacrylate*, which is used to make aquarium walls and ice hockey rink "glass."

A **monomer** is a single molecule capable of combining with other similar molecules.

- One common type of monomer is an alkene or olefin molecule, which contains a carbon-carbon double bond.

EXAMPLE:

Styrene monomer is a simple liquid. When it polymerizes, it becomes polystyrene, the solid that is used in Styrofoam™ cups and restaurant take-out boxes.

Quick Fact

The word "polymer" comes from two Greek roots: "poly," which means "many," and "mer," which means "parts." Literally, polymer translates into "many parts."

Similarly, "monomer" means "one part."

SYNTHESIZING POLYMERS

The two main methods of synthesizing a polymer (combining monomers to create a polymer) are addition polymerization and condensation polymerization.

Addition polymerization (chain polymerization) is the bonding of monomers to form giant molecules without byproducts.

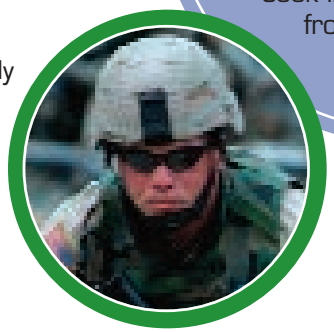
- Monomers are added one by one to the active site on the growing polymer chain.
- Polyethylene and polypropylene are addition polymers used to make various consumer products, including trash bags and plastic containers.
- Polystyrene, as mentioned above, is another example of an addition polymer.

Condensation polymerization (step polymerization) is the combining of monomers that results in the production of some additional byproduct, such as water.

- A common condensation polymer is nylon-6,6, the most widely used of all synthetic polymers.
- Kevlar is an important condensation polymer used for bullet-resistant vests and protective helmets.

Think About It...

What were military helmets made of before the advanced Kevlar design? What design properties does an engineer seek in a helmet, apart from being bullet-resistant?



PLASTICS

Plastics are organic compounds produced by polymerization which can be molded, cast into shapes, or drawn into fibers. The two basic types of plastics are thermosetting plastics (thermosets) and thermoplastics.

Thermosets are plastics that retain their shape after being formed through heat and pressure. Thermosets cannot be remolded.

- Strong cross-linked bonds are formed during the initial molding process, giving the material a stable structure. **Cross-linked bonds** are covalent bonds connecting two nearby chains of a large molecule, such as a polymer.
- Polyesters are a type of thermosetting plastic that can be combined with fiberglass to produce a glass reinforced plastic (GRP). GRP is used in car bodies, sailboats, and furniture.

Thermoplastics are plastics that soften when heated and harden when cooled. Thermoplastics are fully recyclable because they can be remolded.

- Acrylics are thermoplastics available in a variety of colors and forms. Acrylics withstand weather and are stable in sunlight. Transparent acrylic can be as clear as fine optical glass and is used in optical equipment, such as cameras.

Some plastics come from materials of biological origin, such as starch and lactic acid.

- **Biodegradable plastics:** plastics that can be broken down over time in the presence of water and/or enzymes.
- Biodegradable plastics have become increasingly popular as people seek to make convenient ways of life fit with environmentally-friendly lifestyles.

BIOPOLYMERS

Nature relies on polymers too. The larger size of polymeric molecules provides strength and more advanced functions.

Biopolymers are a group of polymers found in or produced by living organisms.

- Biopolymers include starch and cellulose.
- DNA and RNA are examples of biopolymers found in the human body. Other important biopolymers in the human body are proteins.

Quick Fact

One of the most interesting properties of polymers is their toughness. If you've ever dropped a water bottle or shampoo bottle, it most likely did not break.

Polymers have also allowed more effective products to be created. Milk containers, for example used to be made of glass. The old glass containers would shatter, but the new plastic jugs are much more likely to survive a fall.

Think About It...

Some would say that plastics are *too* durable. How can you dispose of plastic milk cartons or containers in an environmentally friendly way?

Quick Fact

Biodegradable plastics (bioplastics) are not found naturally in living organisms. They are polymerized synthetically using renewable materials.

RUBBER

Natural rubber is a stretchy polymer made from a milky-looking substance (latex) found in certain tropical trees. However, many rubber products today are made from synthetic rubbers.

In 1839, Charles Goodyear accidentally dropped a mixture of natural rubber and sulfur onto a hot stove and discovered that the rubber became stronger and more elastic. Goodyear named this process *vulcanization* after the Roman god of fire and the volcano.

- Vulcanization results from cross-linking in the polymer, where the sulfur forms bridges (bonds) between strands of the polymer. This prevents strands of the polymer from constantly being in motion and provides some structure to the molecule.
- The properties of rubber can be adjusted by controlling the amount of sulfur used in vulcanization.
  - Rubber made with 1–3% sulfur is soft and stretchy. It is used in rubber bands.
  - With 3–10% sulfur, the rubber hardens enough to make good tires.
  - With 20–30% sulfur, the rubber becomes a hard synthetic plastic.
- Goodyear's process made rubber waterproof and cold resistant. It opened the door for an enormous rubber goods market.

Quick Fact

The term "elastomer" is often used interchangeably with rubber and means "stretchy pieces."

HISTORY: **SERENDIPITY—LUCK IN SCIENCE**

Just as with Charles Goodyear's accidental discovery of the vulcanization process, other scientists have made fortunate accidental discoveries.

- The Dow Chemical Company discovered Saran™ unexpectedly. Dow chemists were researching the tensile strengths of plastic materials and accidentally synthesized one that tore very easily. Saran™ wrap became widely used for covering food products and keeping them from spoiling. The easy-to-tear property actually turned out to be a benefit.
- The polymer Teflon® (the coating on non-stick pots and pans) was discovered accidentally by scientists at DuPont. They were developing new chlorofluorocarbon (CFC) refrigerants. When they couldn't get one of their reactants to come out of its pressurized tank, they cut open the tank. They discovered that the gas had polymerized, forming a solid that was almost completely unreactive.

Quick Fact

Tensile strength is a measure of the maximum force a material can withstand while being pulled or stretched before breaking or tearing.

PHARMACEUTICALS

Over the years, scientists have developed various substances to help fight illness and disease. A **pharmaceutical** is any chemical substance used in the diagnosis, treatment, cure, or prevention of a disease. Pharmaceuticals are also used to correct organic functions that are not working properly. These are commonly known as medicines, medications, or pharmaceutical drugs.

Pharmaceuticals are important to our health but, like any chemical substance, they can be hazardous if misused, so it is important that people understand how to safely handle and use medicines.

CLASSIFICATION OF PHARMACEUTICALS

Pharmaceuticals can be classified in a number of ways. In the United States, laws require pharmaceuticals to be classified as **over-the-counter (OTC) medications** or **prescription medications**.

- There are usually no restrictions on the purchase of OTC medications. They are located in the regular shopping aisles of grocery and all-purpose stores.
- Prescription medications can only be prescribed by a licensed medical practitioner and distributed through a pharmacy. Prescribed medicines are sold in the amount specified by the medical practitioner and are kept behind a pharmacy counter or ordered directly from manufacturers.

Both OTC and prescription medicines are produced in different forms.

- Many pharmaceuticals are produced in solid form and are sold as pills, tablets, or capsules.
  - The solid form of a pharmaceutical compound is often more stable than other forms. Compounds in solids are less likely to react with other substances, especially when stored inside a capsule.
- Some pharmaceuticals are dissolved in water or another solvent so they can be taken in liquid form.
  - Liquid medicines may be taken either by mouth or intravenously (into the blood through a vein).
  - The intravenous method is often used when time is critical. This method acts the fastest because the fluid or medicine enters the bloodstream directly.
- Pharmaceuticals are also produced as colloidal mixtures, in which minute particles of one subsance are spread evenly throughout another substance.
  - Creams, lotions, and ointments applied to the skin are called topical medicines. These gels and emulsions are rubbed onto injured or damaged skin and help to heal the skin as they are absorbed.
  - Aerosol sprays are used to deliver medicine into the respiratory system. Asthma inhalers and allergy nose sprays are commonly used aerosol medicines.

Think About It...

Why are pharmaceutical compounds less reactive when in solid form? How does the kinetic energy of particles in a solid compare to the kinetic energy of particles in a liquid?

Quick Fact

Dairy products, such as milk and cream, can prevent the absorption of certain antibiotics. Grapefruit juice prevents the breakdown and use of many different medicines in the body.

The most common way to classify pharmaceuticals is by therapeutic use, which describes how a medicine is used. "Therapeutic use" simply means what illness, disease, or symptom the medicine can help treat or heal.

Examples of common categories based on therapeutic use are presented in the table below:

Classification	Therapeutic Use	Active Ingredients & Examples
Analgesics	Provide pain relief without loss of consciousness	Acetaminophen (Tylenol®), aspirin, ibuprofen (Advil®), morphine
Antibiotics	Kill and prevent the growth of bacteria	Cephalosporins, penicillins (including amoxicillin), tetracyclines
Antihistimines	Treat some allergic reactions; target the immune system response (production of histamines) that leads to allergy symptoms	Diphenhydramine (Benadryl®), fexofenadine (Allegra®), loratidine (Claritin®)
Antitussive medicines	Suppress or relieve a cough	Dextromethorphan (Robitussin®, Pediacare®)
Cardiovascular medicines • Antiarrhythmics • Anti-hypertensives	Help with proper heart function and control heart disease • Treat abnormal heartbeats • Control blood pressure	• Flecainide (Tambocor®) • Amlodipine (Norvasc®, Lotrel®), enalapril (Vasotec®)
Gastrointestinal medicines • Antacids • Anti-ulcer medicines	Help with proper functioning of the digestive system • Neutralize excess stomach acid • Reduce the amount of acid produced by the stomach	• Calcium carbonate (Tums®, Caltrate®), milk of magnesia • Famotidine (Pepcid®), omeprazole (Prilosec®)
Hormone medications • Adrenocorticosteroids • Insulin	Copy the effects of natural hormones to properly regulate body functions • Regulate the adrenal gland • Regulates blood sugar; controls diabetes	• Adrenocorticosteroids (DHEA, cortisone) • Insulin
Vaccines	Enhance immunity to or prevent a certain disease	Influenza (flu) vaccine, IPV (inactivated polio vaccine), MMR (measles/mumps/rubella) vaccine

THE PHARMACEUTICAL INDUSTRY

For pharmaceutical companies, discovering and developing new medicines can be a long, expensive, and risky process. To encourage companies to continue conducting research and taking these risks, any new pharmaceutical approved by the Food and Drug Administration (FDA) can be patented. A **patent** prevents other companies from copying the new medicine for a number of years, which allows the manufacturers to sell the medication and make up for the significant development costs. Once the patent expires, the medication becomes a generic drug and can be produced and sold by any company.

Producing a new pharmaceutical requires three main components: drug discovery, drug development, and drug manufacturing.

- **Drug discovery** is the process that leads to the design or discovery of a new pharmaceutical. Discovery often starts by finding the active ingredient in a natural medicine or by researching the activity of a disease or illness at the molecular level. New pharmaceuticals are also often discovered by accident. The earliest stages of drug discovery often occur at universities or research institutions. Once a potential new pharmaceutical has been identified and tested, it moves into the development stage.
- **Drug development** includes activities that determine whether a pharmaceutical is safe and suitable as a medicine. This process includes clinical trials and is mainly carried out by pharmaceutical companies. If a pharmaceutical successfully passes the tests and is approved by the FDA, it moves into the manufacturing stage.
- **Drug manufacturing** is the point at which pharmaceuticals are mass produced and packaged for sale.

NOTES

HISTORY: **MEDICINE & PHARMACEUTICALS**

The history of medicine goes back a long way. Archeologists have evidence of medical practices from the Bronze Age in China (between 2000 and 800 B.C.). They have found collections of seeds, stone surgical tools, and medical records on oracle bones. Following that period, written records show that the practice of medicine became an independent profession in China.

Historians have found written records on papyrus from ancient Egyptian times. This evidence shows that the Egyptians knew a lot about the human body, healing herbs, and how to fix physical injuries. The Ebers Papyrus, believed to be from about 1550 B.C., is considered to be the most complete medical record from ancient Egypt. It includes information on a variety of illnesses and treatments, including crocodile bites and asthma. The papyrus shows early evidence of a systematic approach to health.

Quick Fact

The ancient Egyptians knew of the active ingredient in aspirin long before it became a pharmaceutical drug. They made a tea from willow bark to relieve pain. Willow trees contain salicyclic acid, which reduces pain, fever, and inflammation. Today, a derivative of salicyclic acid is sold as aspirin.

The basis for the majority of modern Western medicine can be traced to classical Greece. During this period, Greek medicine changed from divine and mystical healing to observation and methods based on logic. One of the most famous Greek physicians was Hippocrates. Although little is known about his life, many historians agree that he played a major role in bringing about this change in medical practices. Greek doctors who were influenced by Hippocrates' teachings would study the case history of their patients and ask questions to find out more before treating them.

Quick Fact

Today, doctors in the U.S. pledge to "do no harm." Many resources state that this pledge comes from the Hippocratic Oath. However, it is not actually a part of the oath. Still, even though this line is not a part of his oath, it was a part of Hippocrates' teachings.

The knowledge of the Egyptians and Greeks was passed down to the Romans, who preserved and improved on these medical skills. One of the most famous early pharmacists was Galen. From approximately 130–200 A.D., he practiced and taught medicine and pharmacy in Rome. However, the first drug store is believed to have been opened in 754 A.D. by Arabian pharmacists. Subsequently, drug stores began to appear in other areas across the Middle East and Europe. During the 16th century, the practice and use of pharmaceuticals grew quickly. In 1617, possibly the first pharmacists' group was established—the Society of Apothecaries in London. By the 1800s, many small drug stores in North America and Europe grew into large pharmaceutical companies. Among the earliest modern pharmaceuticals were anesthetics. An anesthetic is used to temporarily block or reduce sensation, including pain.

NOTES

SECTION VII:
ENERGY

OBJECTIVES

- Define the law of conservation of energy.
- Identify and describe types of energy.
- Explain specific heat and use the specific heat equation for calculations.
- Identify different types of electromagnetic waves and explain their uses.
- Describe the components and flow of charges within an electrochemical cell.

Energy is defined as the capacity to do work or produce heat. Energy may take different forms, including light, sound, electricity, chemical bonds, mechanical energy, and thermal energy.

- **Mechanical energy** is associated with the movement or position of objects. It includes both kinetic energy and gravitational potential energy of an object.
- **Thermal energy** is associated with the random motion of particles. It is the total internal energy of a substance that responds to a change in temperature. Remember, it is related to but is not the same as heat or temperature.

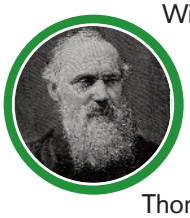
Energy can be converted from one form to another.

- **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:

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. The electricity may be turned into light 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.

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:

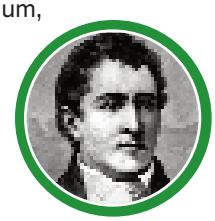
- **Conduction:** the transfer of energy by collisions between nearby atoms.
  - Conduction is the dominant form of heat transfer in solid matter.
  - Conduction causes the metal handle of a pot on a stove to become warm. Heat moves through the metal atoms that make up the pot and excites the atoms in 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.

As with any other energy change, the transfer of heat can be measured in joules. However, in many fields and industries, non-SI units (such as calories and British Thermal Units) are still preferred.

- **Calorie:** a calorie is the quantity of heat needed to increase the temperature of one gram of liquid water one degree Celsius.
- **British Thermal Unit (BTU):** the quantity of heat needed to increase the temperature of a pound of liquid water one degree Fahrenheit. The BTU is the unit commonly used in the United States.
  - A BTU is equivalent to 252 heat calories.
  - BTUs are also used to describe cooling power. The air-cooling power of an air conditioning system describes the amount of thermal energy removed from an area.
  - A 75,000 BTU heater and a 75,000 BTU air conditioner have the same capacity.

Quick Fact

Since a food calorie (a "Calorie" with a capital C) equals 1,000 thermal calories, then with 1 Calorie (or 1 *kilocalorie*), you can increase the temperature of one *kilogram* of water by one degree Celsius.

SPECIFIC HEAT

Specific heat is an important physical property of matter related to energy. The **specific heat** of any substance is the amount of heat required to raise one gram of the substance one degree Celsius. Therefore, every substance has its own specific heat.

The following equation can be used to calculate a substance's specific heat:

$$c = \frac{q}{m\,\Delta T}$$

In the equation, **c** is the substance's specific heat, **q** is the amount of heat added (or absorbed), **m** is the substance's mass, and **ΔT** is the substance's change in temperature.

Quick Fact

Remember, heat is the flow or transfer of energy. That is why it is measured in joules (the same units as energy)!

EXAMPLE:

To calculate the amount of heat absorbed when you heat a cup of water to make tea, use the specific heat equation. As noted earlier, one calorie (4.184 joules) is needed to raise the temperature of one gram of water by one degree Celsius. That 4.184 J/(g × °C) is the specific heat of water. Then, you use a thermometer to measure the starting and ending temperature of the water at 40 °C and 65 °C. You also know that the cup holds 250 grams of water. Next, you can rearrange the specific heat formula to calculate the amount of heat absorbed (q), as shown on the following page.

To solve for the amount of heat absorbed, multiply the mass of the water, the specific heat of water, and the change in temperature:

$$q = m \times c \times \Delta T$$

$$q = 250\ g \times 4.184 \frac{J}{(g \times °C)} \times (65\ °C - 40\ °C)$$

$$q = 250\ g \times 4.184 \frac{J}{(g \times °C)} \times (25\ °C)$$

$$q = 2.6 \times 10^4\ J$$

Therefore, 26,000 joules of energy were absorbed during the process.

Quick Fact

In the lab, a calorimeter can be used to determine the amount of heat absorbed or released during a physical or chemical process. A calorimeter is an insulated device used to find the temperature change in a system. Scientists can determine the specific heat of an unknown substance in a reaction using a calorimeter.

ELECTROMAGNETIC WAVES

Electromagnetic waves carry energy through space. They are characterized by wavelength and frequency.

- **Wavelength:** the distance between one wave crest (top of the wave) and the next or between one wave trough (bottom of the wave) and the next.
- **Frequency:** the number of complete waves or pulses that pass a given point per second.

The product of the wavelength and frequency is a constant, c, the speed of light (3.00×10^8 m/sec).

HISTORY: **MICHAEL FARADAY** (1791–1867)

Michael Faraday discovered electromagnetism by moving a magnet inside a wire coil to create electricity. Based on this discovery, he built the first electric motor.

Faraday developed the concept of a "field" to describe magnetic and electric forces. He also pioneered the field of electrochemistry. He introduced several words that we still use today to discuss electricity: ion, electrode, cathode, and anode.

To honor his accomplishments, a unit of electricity was named after him. The "farad" measures capacitance, an amount of electrical charge.

HISTORY: **MAX PLANCK** (1858–1947)

Max Planck was a German physicist and is often regarded as the father of quantum physics. In 1900, he hypothesized that the energy of an atom can be released or absorbed only in specific quantities which he named quanta (the plural of "quantum"). His work generated an equation that is still used today to calculate energy of a quantum. It includes Planck's constant.

Planck received the Nobel Prize in physics in 1918 for his quantum theory. He received the award after his theory had been successfully applied to the photoelectric effect by Albert Einstein and to the atom by Niels Bohr.

TYPES OF ELECTROMAGNETIC RADIATION

Some types of electromagnetic radiation, in order of decreasing frequency (high to low) and increasing wavelength (short to long) are:

TYPES OF ELECTROMAGNETIC RADIATION

Type	Wavelength
Gamma rays	~ 10^{-10} m (meters) and below
X-rays	~ 10^{-10} to 10^{-8} m
Ultraviolet light	2×10^{-7} to 4×10^{-7} m
Visible light	4×10^{-7} to 7×10^{-7} m
Infrared light	~ 10^{-6} m to 10^{-4} m
Radar, microwaves	~ 10^{-3} m to 10 m
Radio waves	~ 10 m and above

GAMMA RAYS: electromagnetic waves with the shortest wavelengths and highest energy (they have more energy than any other wave in the electromagnetic spectrum). They are released by radioactive atomic nuclei. They are also produced by the radioactive decay of other subatomic particles. Gamma rays may also be called gamma photons.

- They are the most penetrating electromagnetic waves. Therefore, they easily pass through many materials, including the human body.
- They have no mass and no electrical charge. They are pure electromagnetic energy.
- Gamma rays can kill living cells. Therefore, they are used by doctors to kill cancerous cells in cancer patients.
- Substances with a very high density, like lead, are commonly used to slow or stop gamma rays.

Quick Fact

While gamma rays and X-rays have many similarities, they have different origins. Gamma rays originate in (come from) the nucleus. X-rays originate in the electron fields surrounding the nucleus. X-rays can also be produced by machines.

X-RAYS: electromagnetic waves that have very short wavelengths and high energy. They tend to be emitted as a result of the movement of an atom's electrons.

- When you have an X-ray photograph taken at a hospital, X-ray sensitive film is put on one side of your body. Then, X-rays are passed through you. Your bones and teeth are dense and will absorb more X-rays than your skin. As a result, silhouettes of your bones or teeth are left on the X-ray film. Your skin appears transparent.
- The thickness of the earth's atmosphere prevents X-rays from passing through to the earth's surface.

Quick Fact

Metals absorb even more X-rays than bone, which is why metal cavity fillings can be clearly seen on dental X-rays.

HISTORY: **WILHELM CONRAD ROENTGEN** (1845–1923)

X-rays were first observed and documented by the German scientist Wilhelm Conrad Roentgen. He discovered them by accident when experimenting with vacuum tubes. His discovery sparked excitement across the world and medical uses were immediately explored.

Roentgen refused to take out any patents related to his discovery on moral grounds. He did not even want the rays to be named after him. In 1901, he received the first Nobel Prize for physics. In November 2004, the 111th chemical element, Roentgenium, was named after him.

ULTRAVIOLET (UV) RADIATION: electromagnetic waves that fall in the short wavelength range between 200 and 400 nanometers.

- The sun is our primary source of natural UV radiation.
- Exposure to UV light causes skin pigments to darken (producing a suntan). In excess, it can lead to skin cancer.
- Physicists classify UV light into three types, based on wavelength:
  - UVC (290 to 200 nm)
  - UVB (320 to 290 nm)
  - UVA (400 to 320 nm)
- UV light with a shorter wavelength has greater energy and can do more damage.

Quick Fact

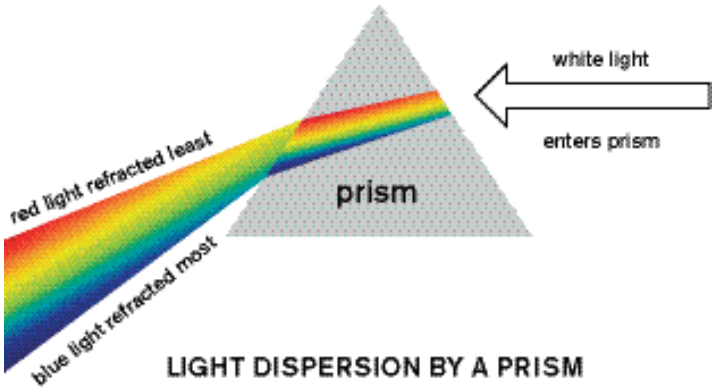
The molecules in sunscreen absorb most UVB light and prevent it from reaching the skin. Sunscreens are typically classified by their "SPF" (Sun Protection Factor). The higher the SPF, the better your skin is protected. Doctors recommend sunscreen with an SPF of 15 or higher.

EXAMPLE:

Direct exposure to UVC for a significant length of time would destroy the skin. Fortunately, UVC is completely absorbed by gases in the atmosphere before it reaches the ground. The longer wavelengths of UVB and UVA pass right through the atmosphere, even on a cloudy day (that's why you can still get sunburned on a cloudy or hazy day).

VISIBLE LIGHT (WHITE LIGHT): a combination of waves that can be detected by the human eye. Wavelengths of visible light extend from about 400 nm for violet light to 700 nm for red light.

- White light may be split into different colors by passing it through a prism. The order of the resulting colors is: red, orange, yellow, green, blue, indigo, and violet.



LIGHT DISPERSION BY A PRISM

INFRARED (IR) RADIATION: electromagnetic waves that cannot be seen by the human eye but are often sensed as heat.

- IR radiation falls in the long wavelength range of the electromagnetic spectrum.
- "Near infrared" waves have wavelengths closer to visible light and are used in TV remotes. "Far infrared" waves are thermal and are closer to the wavelength of microwaves.
- IR radiation is used:
  - In medical imaging to measure skin temperatures.
  - In meteorological imaging to measure surface temperatures of different land and water features.
  - As an industrial heat source for some cooking and drying processes.

Quick Fact

Astronomers have found that IR radiation is quite useful for exploring areas of the universe surrounded by clouds of gas and dust. The longer wavelengths of IR radiation can pass through these clouds, revealing what was invisible before.

MICROWAVES: electromagnetic waves with wavelengths between infrared radiation and radio waves.

- Microwaves are used in satellites because they can pass through fog, light rain, and clouds. Visible light, on the other hand, is blocked by rain and fog.
- Microwaves can be measured conveniently using inches or centimeters.
  - Shorter microwaves (only a few inches long) are used for remote sensing, as in radar. (For example, the Doppler radar is used in weather forecasts.)
- Microwave ovens are found in many household kitchens. They get their name because they use long microwaves (about a foot in length) to heat food. The microwaves heat the food by causing the rotation of water molecules.

RADIO WAVES: electromagnetic waves with the longest wavelengths in the electromagnetic spectrum. Some radio waves are only a few millimeters long; others extend over 100 meters (longer than a football field!).

- Radio waves are used for many different types of communication, such as transmitting music to radios or carrying signals to TVs and cell phones.
- Radio wave frequencies (very low energy) excite the nuclear spin transitions observed in:
  - *Nuclear Magnetic Resonance (NMR) spectroscopy:* a technique for determining the structure of organic compounds.
  - *Magnetic Resonance Imaging (MRI):* a medical imaging technique for observing the structure and function of the body.

ELECTROCHEMISTRY

Electrochemistry is the study of oxidation-reduction (redox) processes in which chemical energy is converted into electrical energy or electrical energy is converted into chemical energy. The converted energy can be used to power devices or to cause a chemical change. Batteries are examples of electrochemistry in action. They convert chemical energy to electrical energy to power things like cars, computers, and cell phones.

Each part of a redox reaction—the oxidation reaction and the reduction reaction— is essential to electrochemistry. Individually, they are called half-reactions.

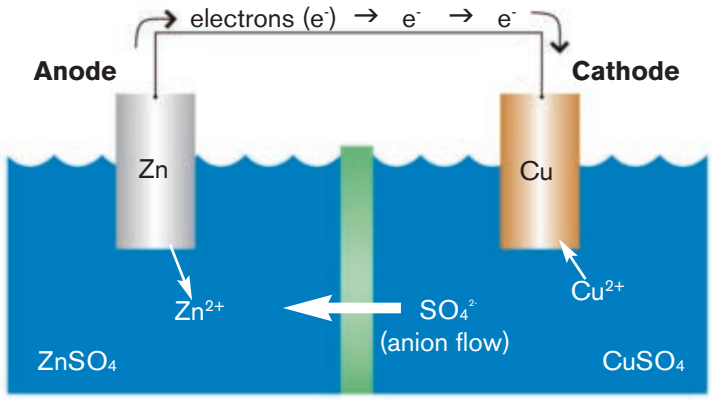
ELECTROCHEMICAL CELLS

An **electrochemical cell** is any device that uses redox reactions to produce electrical energy. These are not cells like in biology. An electrochemical cell is made up of two main parts called half-cells. In one half-cell, the oxidation half-reaction occurs. In the other half-cell, the reduction half-reaction occurs. Both cells have an electrode placed in an ion-containing solution (an electrolyte).

- An **electrode** is a conductor that passes electrical currents between a metallic and nonmetallic part of a circuit.
  - The electrode where the oxidation reaction takes place is called the **anode**. It gives up electrons.
  - The electrode where the reduction reaction occurs is called the **cathode**. It takes in electrons.
- An **electrolyte** is a chemical substance that easily forms ions in a solution. An electrolyte solution can carry an electric current via the movement of the ions in the solution. Electrolytes are used to promote the reactions in each half-cell. As the redox reactions occur, positive charges build up around the anode, and negative charges build up around the cathode. The ions in the electrolyte solution neutralize these charges. This process helps the electrons flow and the reactions to continue.

There are many different types of electrochemical cells. Two examples are explained below.

Porous Disk



The disk between the solutions prevents the metal ions from moving between the electrodes. However, it allows the sulfate ions to flow through.

In the image above, zinc (the anode) is placed in an electrolyte solution of zinc sulfate. Copper (the cathode) is placed in an electrolyte solution of copper sulfate. Zinc loses electrons more easily than copper, so electrons will begin to flow from zinc to copper, as shown below.

When a zinc atom oxidizes, it loses two electrons to become a zinc cation and moves into the solution as Zn^{2+}. The "lost" electrons flow through a metal wire to the copper cathode. The copper cathode takes in a copper cation (Cu^{2+}) from the copper sulfate solution, which accepts two of the incoming electrons to become Cu. Thus, the copper ions are reduced. The reduction of the copper ions leads to a buildup of negative sulfate ions around the cathode.

For the redox reactions to continue, sulfate anions move from the copper side through a porous disk to the positive zinc half-cell. This creates a continuous flow of anions from the right (cathode side) to the left (anode side). As they flow to the left side, the anions electrically neutralize the zinc cations, which allows the process to repeat.

The process can be represented by two half-reactions:

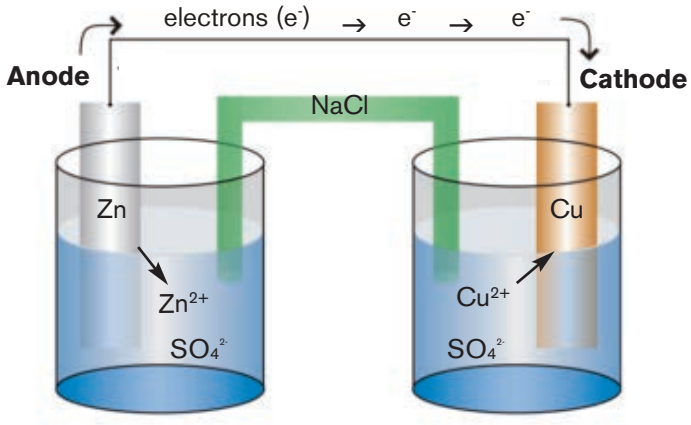
Oxidation half reaction (anode): $Zn \rightarrow Zn^{2+} + 2e^-$

Reduction half reaction (cathode): $Cu^{2+} + 2e^- \rightarrow Cu$

Overall redox reaction: $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$

Salt Bridge

This setup is the same as the first, but uses a salt bridge rather than a porous disk. A salt bridge allows each solution to keep a balanced charge. Salt bridges are often inverted U- tubes filled with a salt. The most commonly used salt is KNO_3.



The salt bridge is made of sodium chloride. Instead of having sulfate anions flow from one solutions to the other as shown in the previous example, the salt provides the anions (Cl^-) needed to neutralize the zinc solution and the cations (Na^+) needed to neutralize the copper solution.

ELECTROPLATING

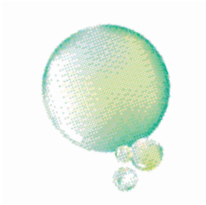
Electroplating is a process used to deposit a protective or decorative layer on an object (usually a metal object). The object to be plated is the cathode. The plating substance (the substance layered on the other object) is the anode. A power source (usually a battery) oxidizes the anode into ions by removing electrons. Then the ions are reduced at the cathode. This creates a thin layer on the object being plated. For the coating to be even across the entire surface, the power source must have a consistent current.

EXAMPLE:

Let's consider plating a metal spoon with pure silver. The spoon is the cathode, and the silver is the anode. A battery is used to oxidize the silver sample. The silver ions are then reduced back to silver metal on the spoon, creating a thin layer of silver that covers the spoon.

Quick Fact

You can plate things like silverware or jewelry with all kinds of metals. The most common plating metals are silver and gold.



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