COMPETENCY 1.0 KNOWLEDGE OF THE STRUCTURE AND BEHAVIOR OF MATTER

SKILL 1.1 Identify the physical and chemical properties of matter (e.g. mass, volume, density, chemical reactivity).

Everything in our world is made up of **matter**, whether it is a rock, a building, an animal, or a person. Matter is defined by its characteristics: It takes up space and it has mass.

Mass is a measure of the amount of matter in an object. Two objects of equal mass will balance each other on a simple balance scale no matter where the scale is located. For instance, two rocks with the same amount of mass that are in balance on earth will also be in balance on the moon. They will feel heavier on earth than on the moon because of the gravitational pull of the earth. So, although the two rocks have the same mass, they will have different **weight.**

Weight is the measure of the earth's pull of gravity on an object. It can also be defined as the pull of gravity between other bodies. The units of weight measurement commonly used are the pound (English measure) and the kilogram (metric measure).

In addition to mass, matter also has the property of volume. **Volume** is the amount of cubic space that an object occupies. Volume and mass together give a more exact description of the object. Two objects may have the same volume, but different mass, or the same mass but different volumes, etc. For instance, consider two cubes that are each one cubic centimeter, one made from plastic, one from lead. They have the same volume, but the lead cube has more mass. The measure that we use to describe the cubes takes into consideration both the mass and the volume. **Density** is the mass of a substance contained per unit of volume. If the density of an object is less than the density of a liquid, the object will float in the liquid. If the object is denser than the liquid, then the object will sink.

Density is stated in grams per cubic centimeter (g/cm^3) where the gram is the standard unit of mass. To find an object's density, you must measure its mass and its volume. Then divide the mass by the volume ($D = m/V$).

To discover an object's density, first use a balance to find its mass. Then calculate its volume. If the object is a regular shape, you can find the volume by multiplying the length, width, and height together. However, if it is an irregular shape, you can find the volume by seeing how much water it displaces. Measure the water in the container before and after the object is submerged. The difference will be the volume of the object.

Specific gravity is the ratio of the density of a substance to the density of water. For instance, the specific density of one liter of turpentine is calculated by comparing its mass (0.81 kg) to the mass of one liter of water (1 kg):

$$\frac{\text{mass of 1 L alcohol}}{\text{mass of 1 L water}} = \frac{0.81 \text{ kg}}{1.00 \text{ kg}} = 0.81$$

Physical properties and chemical properties of matter describe the appearance or behavior of a substance. A **physical property** can be observed without changing the identity of a substance. For instance, you can describe the color, mass, shape, and volume of a book. **Chemical properties** describe the ability of a substance to be changed into new substances. Baking powder goes through a chemical change as it changes into carbon dioxide gas during the baking process.

Matter constantly changes. A **physical change** is a change that does not produce a new substance. The freezing and melting of water is an example of physical change. A **chemical change** (or chemical reaction) is any change of a substance into one or more other substances. Burning materials turn into smoke; a seltzer tablet fizzes into gas bubbles.

SKILL 1.2 Distinguish between the states of matter (e.g., solid, liquid, gas, plasma).

The **phase of matter** (solid, liquid, or gas) is identified by its shape and volume.

A **solid** has a definite shape and volume. A **liquid** has a definite volume, but no shape. A **gas** has no shape or volume because it will spread out to occupy the entire space of whatever container it is in.

While plasma is really a type of gas, its properties are so unique that it is considered a unique phase of matter. **Plasma is a gas that has been ionized**, meaning that at least on electron has been removed from some of its atoms. Plasma shares some characteristics with gas, specifically, the **high kinetic energy** of its molecules. Thus, plasma exists as a diffuse "cloud," though it sometimes includes tiny grains (this is termed dusty plasma). What most distinguishes plasma from gas is that it is **electrically conductive** and exhibits a strong response to electromagnetic fields. This property is a consequence of the **charged particles that result from the removal of electrons** from the molecules in the plasma.

Energy is the ability to cause change in matter. Applying heat to a frozen liquid changes it from solid back to liquid. Continue heating it and it will boil and give off steam, a gas.

Evaporation is the change in phase from liquid to gas. **Condensation** is the change in phase from gas to liquid.

SKILL 1.3 Apply knowledge of the gas laws (e.g., relationships between temperature, pressure, volume of gases).

As a substance is heated, the molecules begin moving faster within the container. As the substance becomes a gas and those molecules hit the sides of the container, pressure builds. **Pressure** is the force exerted on each unit of area of a surface. Pressure is measured in a unit called the **Pascal**. One Pascal (pa) is equal to one Newton of force pushing on one square meter of area. Volume, temperature, and pressure of a gas are related.

Temperature and pressure: As the temperature of a gas increases, its pressure increases. When you drive a car, friction between the road and the tire heats up the air inside the tire. Because the temperature increases, so does the pressure of the air on the inside of the tire.

Temperature and Volume: At a constant pressure, an increase in temperature causes an increase in the volume of a gas. If you apply heat to an enclosed container of gas, the pressure inside the bottle will increase as the heat increases. This is called **Charles' Law**.

These relations (pressure and temperature, and temperature and volume) are **direct variations**. As one component increases (decreases), the other also increases (decreases).

However, pressure and volume vary inversely.

Pressure and volume: At a constant temperature, a decrease in the volume of a gas causes an increase in its pressure. An example of this is a tire pump. The gas pressure inside the pump gets bigger as you press down on the pump handle because you are compressing the gas, or forcing it to exist in a smaller volume. This relationship between pressure and volume is called **Boyle's Law**.

SKILL 1.4 Identify the major discoveries in the development of the atomic theory.

The **atomic theory of matter** suggests that:

1. All matter consists of atoms
2. All atoms of an element are identical
3. Different elements have different atoms
4. Atoms maintain their properties in a chemical reaction

The atomic theory of matter was first suggested by a Greek named **Democritus.** The atomic theory of matter states that matter is made up of tiny, rapidly moving particles. These particles move more quickly when warmer, because temperature is a measure of average kinetic energy of the particles. Warmer molecules therefore move further away from each other, with enough energy to separate from each other more often and for greater distances.

Much later (1780's), a scientist named **John Dalton** expanded on Democritus' idea. Dalton, a school teacher, made some observations about air: air is a mixture of different kinds of gases; these gases do not separate on their own; it is possible to compress gases into a smaller volume. He also thought that particles of different substances must be different from each other and must maintain their own mass when combined with other substances.

Dalton's Model of the Atom:

1. Matter is made up of atoms.
2. Atoms of an element are similar to each other.
3. Atoms of different elements are different from each other.
4. Atoms combine with each other to form new kinds of compounds.

The present model of the atom is much different from Dalton's model.
In the late 1800's, a British scientist named **Thompson** was studying how electric current flowed through a vacuum tube. His hypothesis was:

1. If rays are made of charged particles, then an electric field would attract them.
2. If it is a charged particle, then a magnet will affect its motion.

From his work, Thompson proved that the rays were made of negative particles. These particles were later called electrons.

The results of his experimentation produced **Thompson's Model:** The atom is made of negative particles equally mixed in a sphere of positive material.
In 1986 it was discovered that some elements give off particles with a positive charge. These elements have 7,000 times the mass of electrons. The British scientist **Ernest Rutherford** called these **alpha particles**. He used the alpha particles to test Thompson's model. He hammered gold foil until it was less than 1 mm thick and then fired alpha particles at the foil. He used a telescope and a screen to locate the alpha particles. His hypothesis was that if Thompson's theory was right, then the alpha particles would pass through the foil in a straight line. He found that most particles passed through as expected. However, some appeared to bounce off in another direction. This could not be explained by Thompson's model.

The result of his experiment gave way to **Rutherford's Model**:

1. Most of the atom is empty space. (This explains why most of the alpha particles pass directly through it).
2. The center of the atom contains a nucleus containing most of the mass and all of the positive charge of the atom.
3. The scattering of particles occurs when they collide with the nucleus.
4. The region of the space outside the nucleus is occupied by electrons.
5. The atom is neutral because the protons in the nucleus equal the electrons in the space outside the nucleus.

Based on Rutherford's model, scientists thought that the electrons of an atom might orbit the nucleus much like the planets orbit the sun. If this is true, they could expect two things:

1. As electrons orbit, they give off light energy continuously. If this light energy is passed through a prism, it would produce a band of color.
2. As the orbiting electrons gave off light, they would lose energy and spiral into the nucleus of the atom causing the atom to collapse. Therefore, the atom would take up no space.

No color band was observed. Instead, lines of color and dark lines were observed. Also, since we know that because matter does in fact take up space, then the orbiting atoms cannot collapse into nothing. Another model was necessary to explain the observations. The Danish scientist **Neils Bohr** created a model in 1913. The results of his model are:

1. Electrons orbit the nucleus, but only certain orbits are allowed. An electron in an allowed orbit will not lose energy.
2. When an electron moves from an outer orbit to an inner orbit, it gives off energy.
3. When an electron moves from an inner orbit to an outer orbit, it absorbs energy.

Bohr's model only explains the very simplest atoms, such as hydrogen. Today's more sophisticated atomic model is based upon how waves react.

SKILL 1.5 Identify the characteristics of elements, compounds, and mixtures.

An **element** is a substance that can not be broken down into other substances. To date, scientists have identified 109 elements: 89 are found in nature and 20 are synthetic.

An **atom** is the smallest particle of the element that retains the properties of that element. All of the atoms of a particular element are the same. The atoms of each element are different from the atoms of other elements.

Elements are assigned an identifying symbol of one or two letters. The symbol for oxygen is O and stands for one atom of oxygen. However, because oxygen atoms in nature are joined together is pairs, the symbol O_2 represents oxygen. This pair of oxygen atoms is a molecule. A **molecule** is the smallest particle of substance that can exist independently and has all of the properties of that substance. A molecule of most elements is made up of one atom. However, oxygen, hydrogen, nitrogen, and chlorine molecules are made of two atoms each.

A **compound** is made of two or more elements that have been chemically combined. Atoms join together when elements are chemically combined. The result is that the elements lose their individual identities when they are joined. The compound that they become has different properties.

We use a formula to show the elements of a chemical compound. A **chemical formula** is a shorthand way of showing what is in a compound by using symbols and subscripts. The letter symbols let us know what elements are involved and the number subscript tells how many atoms of each element are involved. No subscript is used if there is only one atom involved. For example, carbon dioxide is made up of one atom of carbon (C) and two atoms of oxygen (O_2), so the formula would be represented as CO_2.

Substances can combine without a chemical change. A **mixture** is any combination of two or more substances in which the substances keep their own properties. A fruit salad is a mixture. So is an ice cream sundae, although you might not recognize each part if it is stirred together. Colognes and perfumes are the other examples. You may not readily recognize the individual elements. However, they can be separated.

Compounds and **mixtures** are similar in that they are made up of two or more substances. However, they have the following opposite characteristics:

Compounds:

1. Made up of one kind of particle
2. Formed during a chemical change
3. Broken down only by chemical changes
4. Properties are different from its parts
5. Has a specific amount of each ingredient.

Mixtures:

1. Made up of two or more particles
2. Not formed by a chemical change
3. Can be separated by physical changes
4. Properties are the same as its parts.

5. Does not have a definite amount of each ingredient.

Common compounds are **acids, bases, salts**, and **oxides** and are classified according to their characteristics.

An **acid** contains hydrogen ions (H+). Although it is never wise to taste a substance to identify it, acids have a sour taste. Vinegar and lemon juice are both acids, and acids occur in many foods in a weak state. Strong acids can burn skin and destroy materials. Common acids include:

Sulfuric acid (H_2SO_4)	-	Used in medicines, alcohol, dyes, and car batteries.
Nitric acid (HNO_3)	-	Used in fertilizers, explosives, cleaning materials.
Carbonic acid (H_2CO_3)	-	Used in soft drinks.
Acetic acid ($HC_2H_3O_2$)	-	Used in making plastics, rubber, photographic film, and as a solvent.

Bases have a bitter taste and the stronger ones feel slippery. Like acids, strong bases can be dangerous and should be handled carefully. All bases contain hydroxyl ions (OH-). Many household cleaning products contain bases. Common bases include:

Sodium hydroxide	$NaOH$	-	Used in making soap, paper, vegetable oils, and refining petroleum.
Ammonium hydroxide	NH_4OH	-	Making deodorants, bleaching compounds, cleaning compounds.
Potassium hydroxide	KOH	-	Making soaps, drugs, dyes, alkaline batteries, and purifying industrial gases.
Calcium hydroxide	$Ca(OH)_2$	-	Making cement and plaster

An **indicator** is a substance that changes color when it comes in contact with an acid or a base. Litmus paper is an indicator. Blue litmus paper turns red in an acid. Red litmus paper turns blue in a base.

A substance that is neither acid nor base is **neutral**. Neutral substances do not change the color of litmus paper.

Salt is formed when an acid and a base combine chemically. Water is also formed. The process is called **neutralization**. Table salt (NaCl) is an example of this process. Salts are also used in toothpaste, Epsom salts, and cream of tartar. Calcium chloride ($CaCl_2$) is used on frozen streets and walkways to melt the ice. **Oxides** are compounds that are formed when oxygen combines with another element. Rust is an oxide formed when oxygen combines with iron.

SKILL 1.6 Apply knowledge of symbols, formulas, and equations for common elements and compounds, and their reactions.

One or more substances are formed during a **chemical reaction**. Also, energy is released during some chemical reactions. Sometimes the energy release is slow and sometimes it is rapid. In a fireworks display, energy is released very rapidly. However, the chemical reaction that produces tarnish on a silver spoon happens very slowly.

Chemical equilibrium is defined as occurring when the quantities of reactants and products are at a ‘steady state’ and no longer shifting, but the reaction may still proceed forward and backward. The rate of forward reaction must equal the rate of backward reaction.

In one kind of chemical reaction, two elements combine to form a new substance. We can represent the reaction and the results in a chemical equation. Carbon and oxygen form carbon dioxide. The equation can be written:

C	+	O_2	$\rightarrow$	CO_2
1 atom of	+	2 atoms of	$\rightarrow$	1 molecule of
carbon		oxygen	$\rightarrow$	carbon dioxide

No matter is ever gained or lost during a chemical reaction; therefore the chemical equation must be *balanced.* This means that there must be the same number of atoms on both sides of the equation. Remember that the subscript numbers indicate the number of atoms in the elements. If there is no subscript, assume there is only one atom.

In a second kind of chemical reaction, the molecules of a substance split forming two or more new substances. An electric current can split water molecules into hydrogen and oxygen gas.

$2H_2O$	$\rightarrow$	$2H_2$	+	O_2
2 molecules	$\rightarrow$	2 molecules	+	1 molecule
of water		of hydrogen		of oxygen

The number of molecules is shown by the number in front of an element or compound. If no number appears, assume that it is 1 molecule.

A third kind of chemical reaction is when elements change places with each other. An example of one element taking the place of another is when iron changes places with copper in the compound copper sulfate:

$CuSo_4$	+	Fe	$\rightarrow$	$FeSO_4$	+	Cu
copper sulfate	+	iron (steel wool)		iron sulfate		copper

Sometimes two sets of elements change places. In this example, an acid and a base are combined:

HCl	+	NaOH	$\rightarrow$	NaCl	+	H_2O
hydrochloric acid		sodium hydroxide		sodium chloride (table salt)		water

Matter can change, but it cannot be created or destroyed. The sample equations show two things:

1. In a chemical reaction, matter is changed into one or more different kinds of matter.
2. The amount of matter present before and after the chemical reaction is the same.

Many chemical reactions give off energy. Like matter, energy can change form but it can be neither created nor destroyed during a chemical reaction. This is the **law of conservation of energy.**

SKILL 1.7 Identify characteristics and functions of the components of an atom.

An **atom** is a nucleus surrounded by a cloud with moving electrons.

The **nucleus** is the center of the atom. The positive particles inside the nucleus are called **protons.** The mass of a proton is about 2,000 times that of the mass of an electron. The number of protons in the nucleus of an atom is called the **atomic number**. All atoms of the same element have the same atomic number.

Neutrons are another type of particle in the nucleus. Neutrons and protons have about the same mass, but neutrons have no charge. Neutrons were discovered because scientists observed that not all atoms in neon gas have the same mass. They had identified isotopes. **Isotopes** of an element have the same number of protons in the nucleus, but have different masses. Neutrons explain the difference in mass. They have mass but no charge.

The mass of matter is measured against a standard mass such as the gram. Scientists measure the mass of an atom by comparing it to that of a standard atom. The result is relative mass. The **relative mass** of an atom is its mass expressed in terms of the mass of the standard atom. The isotope of the element carbon is the standard atom. It has six (6) neutrons and is called carbon-12.It is assigned a mass of 12 atomic mass units (amu). Therefore, the **atomic mass unit (amu)** is the standard unit for measuring the mass of an atom. It is equal to the mass of a carbon atom.

The **mass number** of an atom is the sum of its protons and neutrons. In any element, there is a mixture of isotopes, some having slightly more or slightly fewer protons and neutrons. The **atomic mass** of an element is an average of the mass numbers of its atoms.

The following table summarizes the terms used to describe atomic nuclei:

Term	**Example**	**Meaning**	**Characteristic**
Atomic Number	# proton (p)	same for all atoms of a given element	Carbon (C) atomic number = 6 (6p)
Mass number	# protons + # neutrons (p + n)	changes for different isotopes of an element	C-12 (6p + 6n) C-13 (6p + 7n)
Atomic mass	average mass of the atoms of the element	usually not a whole number	atomic mass of carbon equals 12.011

Each atom has an equal number of electrons (negative) and protons (positive). Therefore, atoms are neutral. Electrons orbiting the nucleus occupy energy levels that are arranged in order and the electrons tend to occupy the lowest energy level available. A **stable electron arrangement** is an atom that has all of its electrons in the lowest possible energy levels.

Each energy level holds a maximum number of electrons. However, an atom with more than one level does not hold more than 8 electrons in its outermost shell.

Level	**Name**	**Max. # of Electrons**
First	K shell	2
Second	L shell	8
Third	M shell	18
Fourth	N shell	32

This can help explain why chemical reactions occur. Atoms react with each other when their outer levels are unfilled. When atoms either exchange or share electrons with each other, these energy levels become filled and the atom becomes more stable.

As an electron gains energy, it moves from one energy level to a higher energy level. The electron can not leave one level until it has enough energy to reach the next level. **Excited electrons** are electrons that have absorbed energy and have moved farther from the nucleus.

Electrons can also lose energy. When they do, they fall to a lower level. However, they can only fall to the lowest level that has room for them. This explains why atoms do not collapse.