Chapter Four: Matter and Energy

**Matter**
Recall that matter
- Has mass
- Takes up space (i.e. has volume)
Matter also has one of four states
- Gas
- Liquid
- Solid
- Plasma  (We will **not** be concerned with the plasma state in this course!)

**States of Matter**
The states of matter are classified by two parameters
- Does it take the shape of its container?
- Does it completely fill its container?

**Gases**
- Take the shape of their container
- Completely fill their container

**Liquids**
- Take the shape of their container
- Do not fill their container completely

**Solids**
- Do not take the shape of their container
- Do not fill their container completely

Which state a substance is in depends on two factors: Temperature and Pressure

Gases are comprised of molecules which generally are far apart from one another, and travel in random paths.
The particles in liquids and solids are much closer together than those of gases
The particles of solids are generally “stuck in place”, but are able to vibrate
Liquid particles freely move across one another

**Changes of State**
Special terms are associated when matter changes from one state to another.
You may be familiar with the term “freezing,” which describes a change from liquid to solid.

Solid   Liquid

Gas
Properties of Matter
We can describe matter in two ways:
By its **chemical properties**, which describe how a type of matter interacts (or “reacts”) with another type of matter.
   For example, hydrogen is able to react with oxygen to form water. Helium reacts with virtually nothing.
By its **physical properties**, which include all non-chemical properties.
   For example, water is a liquid at room temperature, freezes at 0 °C, has a density of 1.0 g/mL, and is both clear (we can see through it) and colorless.

Changes of Matter
Similarly, changes can be classified in the same way as properties:
**Chemical changes** involve a rearrangement of atoms, producing chemical compounds that were not there before.
   When iron (Fe) is exposed to oxygen on a wet day, rust (Fe₂O₃) is formed.
**Physical changes** are those which do not involve a chemical change.
   Boiling water (liquid H₂O changes to gaseous H₂O), glass shattering, a chemical evaporating.

Metals
The metals include many elements found on the left side of the periodic table.
Many metals are known for having the following properties
   They are malleable (meaning they are soft and easily shaped)
   They are ductile (they can be twisted and drawn into a wire)
   They can conduct both electricity and heat.
   They tend to be lustrous (shiny).
All metals are solids at room temperatures except for mercury, which is a liquid.

Nonmetals
Nonmetals are generally found on the right side of the periodic table (except hydrogen, which is placed on the left).
Their properties are generally the opposite of the metals.
   Those which are solids tend to be brittle.
   Most are poor conductors of electricity at room temperature (insulators) and do not conduct heat well.
Some are gases at room temperature; others are solids. Bromine is the only other element which is a liquid.

Metalloids
Metalloids are found between the metals and the nonmetals on the periodic table.
They include B, Si, Ge, As, Sb, and Te.
The properties of the metalloids are often a cross between those of the metals and the nonmetals.
All the metalloids listed are solids at room temperature.
   (I do not include Po and At with the metalloids. They are rather unstable and unimportant to our studies at this point.)
**The Law of Conservation of Mass**

One of the most fundamental statements about matter is described by this law, which states:

“Matter can neither be created nor destroyed in any chemical process”

Another consequence of this law is that one type of atom cannot be changed into another through a chemical reaction.

If you start a chemical process with 10 million hydrogen atoms and 10 million oxygen atoms, then you will end the process with 10 million hydrogen atoms and 10 million oxygen atoms. ALWAYS!

**Energy**

Energy is an important subject in chemistry, as chemical reactions either give off or take in energy. The **Law of Conservation of Energy** states that “Energy can neither be created nor destroyed in a process.”

Energy can be transferred between two systems in two ways

- As work (w), which we will consider as energy put to some specific use, like making a motor run.
- As heat (q), which will be random energy (not directed to some useful purpose), like that given off by your car’s engine.

Any change in energy is just the sum of the work and heat changes.

The SI unit of energy is the Joule (J). Other units include the kJ, and the calorie (cal)

1 calorie = 4.184 Joules

For example, suppose that burning a certain amount of gasoline produces 50 kJ of energy. If only 20 kJ of it goes into doing work in a car engine, the remaining 30 kJ must be lost as heat. Remember, energy cannot be destroyed!

An **exothermic** process is one which gives off more heat than it takes in.

For an exothermic reaction, \( q < 0 \).

For example, consider burning gasoline.

An **endothermic** process is one which brings in more heat than it gives off.

For an endothermic reaction, \( q > 0 \).

**Specific Heat**

Some substances require more energy to raise their temperatures than others. For example, it requires much less energy to raise the temperature of 50 g of aluminum by 10 °C than it would to raise 50 g of water by the same amount.

This difference is represented by a constant called the specific heat, \( c \).
Its units are J/(g °C) or cal/(g °C).

**Transferring Heat**

The amount of heat (q) absorbed or given off by a substance when it changes temperature can be found using the following equation:

\[
q = m \times \Delta T \times c
\]

- \( m \) is the mass of the substance
- \( \Delta T \) is the change in the temperature; it equals (final \( T \) – starting \( T \))
- \( c \) is the specific heat of the substance

Note that heat always flows from an area of high temperature to one of lower temperature!
Example
How much heat is required to raise the temperature of 50.0 g of aluminum from 32 °C to 47 °C? The specific heat of aluminum is 0.215 cal/(g · °C).

A More Difficult Example
A 50.0 g aluminum block is heated to 75 °C, then dropped into a sealed container containing 350 g of water at 15 °C. What will be the temperature of the block when it is finished cooling?

More On Conservation
Note that in the last problem, heat was transferred from the aluminum to the water, but never destroyed. Einstein is credited with the famous equation:

\[ E = mc^2 \]

Where \( E \) is energy, \( m \) is mass, and \( c \) is a constant (the speed of light, not the specific heat!) This shows that matter can be converted to energy. More on Conservation Note however, this will not apply to chemical reactions. We see this with nuclear reactions. In this class, mass is always conserved.
We can now state the Law of Conservation of Mass-Energy:

"Mass and energy can neither be created nor destroyed in a process, though they may be interchanged."

**Kinetic and Potential Energy**

*Kinetic Energy (K.E.)* is the energy of motion. The amount of *K.E.* an object has is described by the formula

\[ K.E. = \frac{1}{2}mv^2 \]

where \( m \) is the object's mass, and \( v \) is its velocity.

*Potential Energy* is the energy of position. Objects may be in a "high energy" position, and can convert this potential energy to kinetic energy while moving to a "lower energy" position.

*Examples:*