CHAPTER 3: MATTER

Active Learning Questions: 1-6, 9, 13-14;

3.1 MATTER

Matter: Anything that has mass and occupies volume

We study matter at different levels:

- **macroscopic**: the level that can be observed with the naked eye
  - e.g. geologists study rocks and stone at the macroscopic level

- **microscopic**: the level that can be observed with a microscope
  - e.g. scientists study tiny animals, plants, or crystals at microscopic level

- **particulate**: at the level of atoms and molecules, also called atomic or molecular level
  - cannot be observed directly even with the most powerful microscopes
  - where the term “nanotechnology” comes from since many atoms and molecules are about a few nanometers in size

<table>
<thead>
<tr>
<th>Macroscopic</th>
<th>Microscopic</th>
<th>Particulate</th>
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<tbody>
<tr>
<td>$1 \times 10^6$ m (1 m)</td>
<td>$1 \times 10^{-9}$ m (1 mm)</td>
<td>$1 \times 10^{-11}$ m (1 pm)</td>
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<tr>
<td>$1 \times 10^{-1}$ m (1 dm)</td>
<td>$1 \times 10^{-6}$ m (1 µm)</td>
<td>$1 \times 10^{-12}$ m (1 pm)</td>
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<td>$1 \times 10^{-2}$ m (1 cm)</td>
<td>$1 \times 10^{-7}$ m (10 µm)</td>
<td>$1 \times 10^{-13}$ m (1 pm)</td>
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<tr>
<td>$1 \times 10^{-3}$ m (1 mm)</td>
<td>$1 \times 10^{-8}$ m (100 nm)</td>
<td>$1 \times 10^{-14}$ m (1 pm)</td>
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Substances like water can be represented using different **symbols** (e.g. H₂O) and **models**.
Matter exists in one of three physical states: solid, liquid, gas

**solid:** Has definite shape and a fixed (or constant) and rigid volume
- Particles only vibrate in place.

**liquid:** Has a fixed (or constant) volume, but its shape can change.
- Takes the shape of its container because particles are moving
- Particles are packed closely together but can move around each other.

**gas:** Volume is variable, and particles are far apart from one another.
- Takes the shape of the container because particles are moving
  → If container volume expands, particles move apart to fill container.
  → If container volume decreases, particles move closer together.
  → Gases are compressible—i.e., can be forced to occupy a smaller volume.
- Particles are in constant random motion.
3.3 ELEMENTS AND COMPOUNDS
3.4 MIXTURES AND PURE SUBSTANCES

We can classify matter into pure substances and mixtures:

pure substance: a single chemical, consisting of only one kind of matter
– There are two types of pure substances: elements and compounds.
  – In the figure below, copper rods are an example of an element, and sugar is an example of a compound.

mixture: consists of two or more elements and/or compounds
– Mixtures can be homogeneous or heterogeneous:
  – Homogeneous mixtures have a uniform appearance and composition because the particles in them mix uniformly (e.g. solutions like sweetened tea below)
  – Heterogeneous mixtures do not have a uniform composition.
    – e.g. chocolate chip cookie, water and C₈H₁₈ mixture below shown as separate layers
elements:
- consist of only one type of atom
- atoms cannot be broken down into smaller components by chemical reaction
  - e.g. copper wire (Cu), sulfur powder (S₈)
  - Examples also include sodium (Na), barium (Ba), hydrogen gas (H₂), oxygen gas (O₂), and chlorine gas (H₂).

compounds:
- consist of more than one type of atom and have a specific chemical formula
- Examples include hydrogen chloride (HCl), water (H₂O), sodium chloride (NaCl) which is table salt, barium chloride (BaCl₂)

Two or more pure substances combine to form mixtures.

mixtures:
- consist of many compounds and/or elements, with no specific formula
- Matter having variable composition with definite or varying properties
  - can be separated into component elements and/or compounds
  - e.g., any alloy like brass, steel, 10K to 18K gold; sea water, carbonated soda; air consists of nitrogen, oxygen, and other trace gases.

The image at the right shows that air is a mixture of about 78% nitrogen (N₂ in blue), 21% oxygen (O₂ in red), and trace gases while salt water consists of salt (charged particles of Na⁺ and Cl⁻) dissolved in water.

Example: Is salt water a homogeneous or heterogeneous mixture?

Explain why.
3.2 PHYSICAL AND CHEMICAL PROPERTIES AND CHANGES

The characteristics that distinguish one substance from another are called **properties**.

**Physical Properties**: inherent characteristics of a substance independent of other substances
- physical state (solid, liquid, gas)
- color
- density
- melting and boiling points
- electrical & heat conductivity
- odor
- hardness
- solubility (does/does not dissolve in water)

**Chemical Properties**: how a substance reacts with other substances
- e.g. hydrogen reacts explosively with oxygen

3.6 How Matter Changes: Physical and Chemical Changes

**physical change**: a process that does not alter the chemical makeup of the starting materials
- Note in the figure below that the H₂O molecules remain H₂O regardless of the physical state (solid, liquid, or gas).
  → Changes in physical state are **physical changes**.

- Other examples of physical changes include hammering gold into foil, dry ice subliming
- Dissolving table salt or sugar in water is also a **physical change**.
- A substance dissolved in water is the fourth physical state, **aqueous**.
Know the terms for transitions from one physical state to another:

- **freezing**: liquid $\rightarrow$ solid
- **condensing**: gas $\rightarrow$ liquid
- **melting**: solid $\rightarrow$ liquid
- **vaporizing**: liquid $\rightarrow$ gas

Two less common transitions:

- **sublimation**: solid $\rightarrow$ gas (e.g. dry ice sublimes)
- **deposition**: gas $\rightarrow$ solid (e.g. water vapor deposits on an icebox)

**chemical change:**

- A process that does change the chemical makeup of the starting materials
- We can show H$_2$ and O$_2$ reacting to form water (H$_2$O) below. Since the H$_2$O has a different chemical makeup than H$_2$ and O$_2$, this is a chemical change.

\[
\text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O}
\]

- Other examples of chemical changes:
  - e.g. oxidation of matter (burning or rusting), release of gas bubbles (fizzing),
  - mixing two solutions to form an insoluble solid (precipitation), and other evidence indicating the starting materials (reactants) were changed to a different substance.
- The following examples are all chemical changes that convert the reactants to completely different compounds and/or elements.

- release of gas bubbles (fizzing)
- formation of insoluble solid (precipitation)
- oxidation (burning or rusting)
Example 1: Consider the following molecular-level representations of different substances:

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For each figure above, indicate if it represents an element, a compound, or a mixture AND if it represents a solid, liquid, or gas.

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<td>element</td>
<td>compound</td>
<td>mixture</td>
<td>solid</td>
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<tr>
<td>B</td>
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<td>mixture</td>
<td>solid</td>
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<td>mixture</td>
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<td>mixture</td>
<td>solid</td>
</tr>
</tbody>
</table>

Ex. 2: Circle all of the following that are chemical changes:

- burning
- condensing
- dissolving
- rusting
- vaporizing
- precipitating
THE LAW OF CONSERVATION OF MASS

Chemical Reaction: \[ \text{REACTANTS} \rightarrow \text{PRODUCTS} \]

(reactants) \[ \rightarrow \] (products)

For the reaction: \[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \]

The reactants are carbon and oxygen gas, and the product is carbon dioxide.

Antoine Lavoisier (1743-1794), a French chemist, carried out experiments on combustion by burning different substances and measuring their masses before and after burning.
- He found that there was no change in the overall mass of the sample and air around it.

→ **Law of Conservation of Mass:** Matter is neither created nor destroyed in a chemical reaction, so mass is conserved.
- Since the atoms are simply rearranged (not created or destroyed) in a chemical reaction, the total mass of the products must always equal the total mass of the reactants.

**Mass of the product(s) in a reaction must be equal to the mass of the reactant(s).**

For example: \[ 11.2 \text{ g hydrogen} + 88.8 \text{ g oxygen} = 100.0 \text{ g water} \]

Ex. 1: Methane burns by reacting with oxygen present in air to produce steam and carbon dioxide gas. Calculate the mass of oxygen that reacts if burning 50.0 g of methane produces 112.3 g of steam and 137.1 g of carbon dioxide.