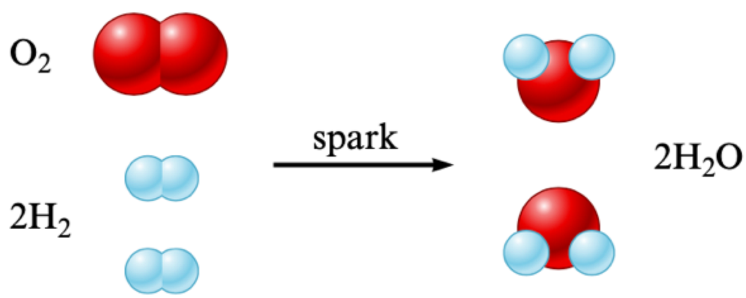
**Chemical Foundations**

## Chemistry

Chemistry is the study of matter and its interactions. There are two fundamental concepts of chemistry:

1. Matter is composed of various types of atoms.
2. One substance changes to another by reorganizing the way the atoms are attached to each other.

Consider, for example, the reaction where hydrogen and oxygen react to form water.




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

## Units of Measurement

Making observations is fundamental to all science. A quantitative observation, or **measurement**, always consists of two parts: a number and a unit. Both parts must be present for the measurement to be meaningful.

In chemistry, we use the SI units, which are based on the metric system and units derived from the metric system. The fundamental SI units are listed below:

| **SI Base Units** | | |
|---|---|---|
| **Base Quantity** | **Base Unit** | **Symbol** |
| Length | meter | *m* |
| Mass | kilogram | *kg* |
| Time | second | *s* |
| Temperature | Kelvin | *K* |
| Amount of Substance | mole | *mol* |
| Electric Current | ampere | *A* |
| Luminous Intensity | candela | *cd* |

Because the fundamental units are not always convenient (for very large or very small numbers), prefixes are used to change the size of the unit. Some of these prefixes are listed below:

| SI Prefixes | | | |
|---|---|---|---|
| **Prefix** | **Symbol** | **Power of 10** | **Example** |
| nano | $n$ | $10^{-9}$ | nanometer ($nm$) |
| micro | $\mu$ | $10^{-6}$ | microgram ($\mu g$) |
| milli | $m$ | $10^{-3}$ | milligram ($mg$) |
| centi | $c$ | $10^{-2}$ | centimeter ($cm$) |
| deci | $d$ | $10^{-1}$ | deciliter ($dL$) |
| **Base Unit** | varies | $10^{0}$ | meter ($m$) |
| kilo | $k$ | $10^{3}$ | kilometer ($km$) |
| mega | $M$ | $10^{6}$ | megagram ($Mg$) |
| giga | $G$ | $10^{9}$ | gigameter ($Gm$) |

**Dimensional Analysis**

It is often necessary to convert a given result from one unit to another. The best way to do this is by a method called dimensional analysis. To illustrate this method, we will consider an example.

**Example 1**
Consider a pin measuring 2.85 cm in length. What is its length in meters?

**Problem-Solving Strategy**
Converting from One Unit to Another

1. To convert from one unit to another, use the equivalence statement that relates the two units.
2. Derive the appropriate unit factor by looking at the direction of the required change (to cancel the unwanted units).
3. Multiply the quantity to be converted by the unit factor to give the quantity with the desired units.

**Example 2**
A student has entered a 10.0 km run. How long is the run in centimeters?

**Example 3**
The speed limit on many highways in Canada is 100 km/h. What is this in meters per second?

## Volume

**Volume** is the amount of three-dimensional space something occupies. There are a few important relationships that we need to know regarding volume.

$$1\ L = 1000\ mL$$

$$1\ mL = 1\ cm^3$$

## Mass and Weight

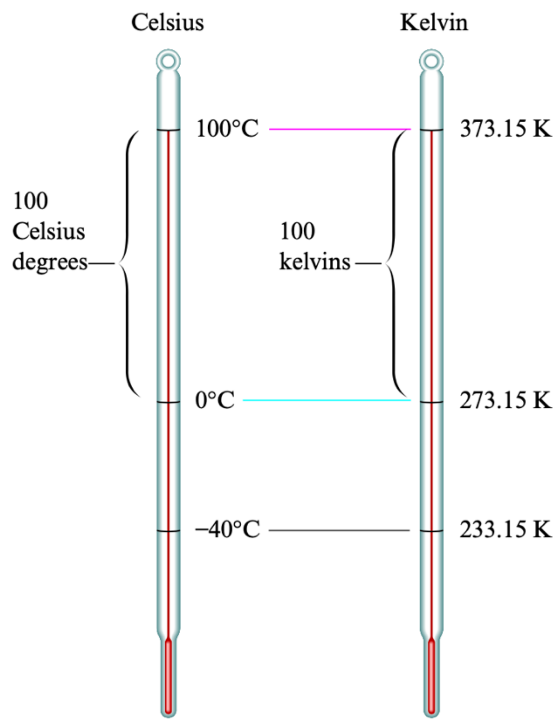
**Mass** is a measure of the resistance of an object to a change in its state of motion. **Weight** is the force that gravity exerts on an object.

$$Mass = \frac{Weight}{9.8\ N/kg} \qquad (on\ Earth)$$

Mass is measured in kilograms $(kg)$, while weight is measured in Newtons $(N)$. The mass of an object is constant, but weight varies with the strength of gravity. Thus, your body would have the same mass on the earth and the moon, but your weight would be much less on the moon than on the earth.

## Temperature

In chemistry, we primarily use two temperature scales: the Celsius scale, and the Kelvin scale. The two temperature scales are defined and compared in the diagram below.




Note that the size of the temperature unit (the degree) is the same for the Kelvin and Celsius scales. The fundamental difference between these two temperature scales is their zero points. Conversion between these two scales simply requires an adjustment for the different zero points.

$$T_K = T_C + 273$$

or

$$T_C = T_K - 273$$

Note: When expressing a temperature in Celsius, the symbol ℃ is used. When expressing a temperature in Kelvin, the symbol $K$ is used (note the lack of degree symbol).

**Example 4**
Normal body temperature is 37.0℃. Convert this temperature to the Kelvin scale.

**Example 5**
Liquid nitrogen has a boiling point of $77\ K$. What is this temperature on the Celsius scale?

**Density**

A property of matter that is often used by chemists to identify a substance is **density**, the mass of substance per unit volume of the substance.

$$Density = \frac{mass}{volume}$$

The density of a liquid can be determined easily by weighing an accurately known volume of liquid, as illustrated in the following example.

**Example 6**
A chemist, trying to identify an unknown liquid, finds that $25.00\ cm^3$ of the substance has a mass of $19.625\ g$ at $20$℃. The following are the names and densities of the compounds that might be the liquid.

| **Compound** | **Density in $g/cm^3$ at $20$℃** |
|---|---|
| Chloroform | 1.492 |
| Diethyl ether | 0.714 |
| Ethanol | 0.789 |
| Isopropyl alcohol | 0.785 |
| Toluene | 0.867 |

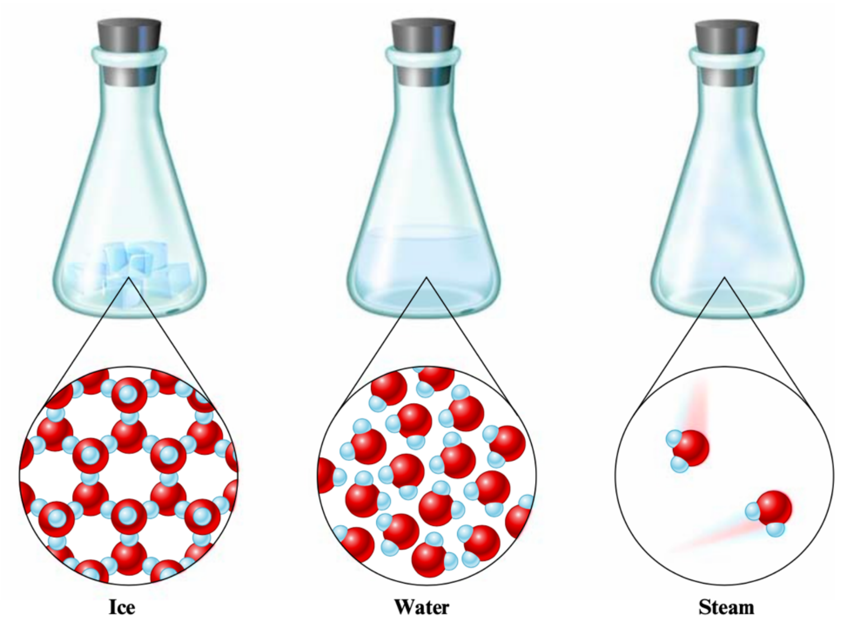
Which of these compounds is the most likely to be the unknown liquid?

## Classification of Matter

**Matter** is best defined as anything occupying space and having mass. It is the material that the universe is made of. This section will introduce basic ideas about the structure of matter and its behavior.

### States of Matter

There are three **states of matter**: solid, liquid, and gas. A **solid** is rigid; it has a fixed volume and shape. A **liquid** has a definite volume but no specific shape; it assumes the shape of its container. A **gas** has no fixed volume or shape; it takes on the shape and volume of its container. Gases are highly compressible, while liquids and solids are only slightly compressible. Molecular level pictures of the three states of water are shown below.




**Solid:** The water molecules are locked into rigid positions and are close together.

**Liquid:** The water molecules are still close together but can move around to some extent.

**Gas:** The water molecules are far apart and move randomly.

Boiling and freezing are physical changes. A **physical change** is a change in the form of a substance, not in its chemical composition.

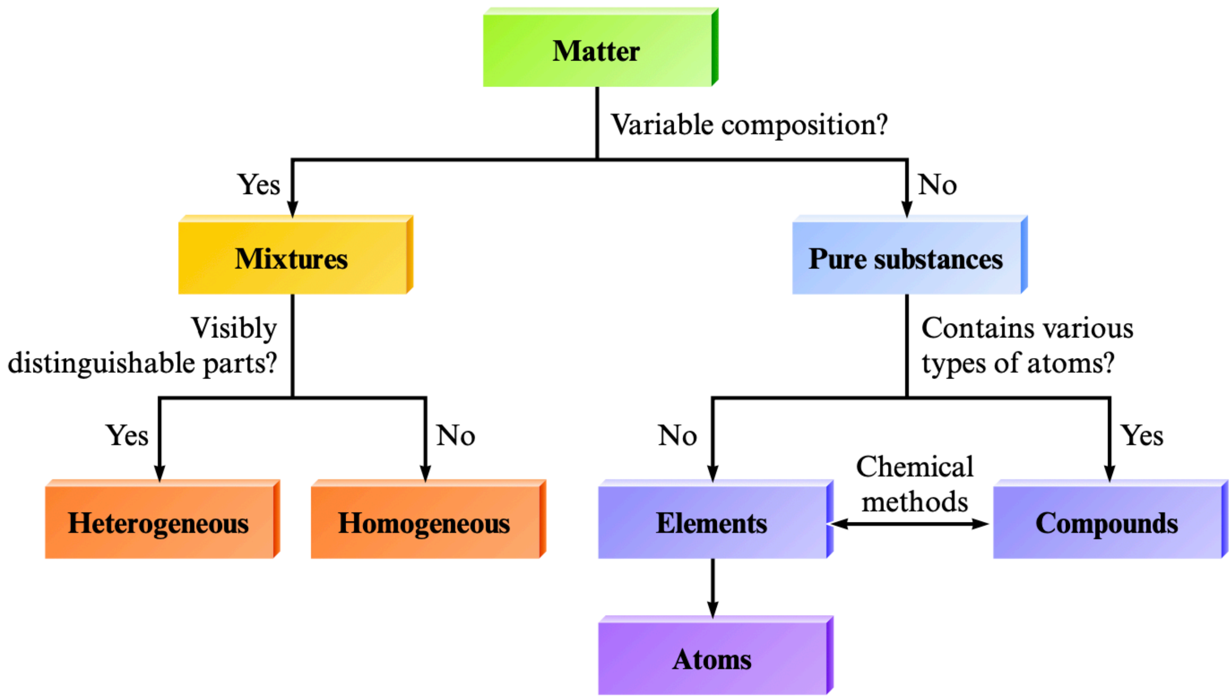
### Elements, Compounds, and Mixtures

A **pure substance** is one with constant composition. Pure substances are either compounds or elements. A **compound** is a pure substance that can be broken down into elements by chemical processes. **Elements** are pure substances that cannot be broken down into simpler substances by chemical means.

Breaking a compound into elements is an example of a chemical change. A **chemical change** is one in which a given substance becomes a new substance or substances with different properties.

Most of the matter around us consists of **mixtures** of pure substances. The main characteristic of a mixture is that it has variable composition. Mixtures can be classified as **homogeneous** (having visibly indistinguishable parts) or **heterogeneous** (having visibly distinguishable parts). A homogeneous mixture is called a **solution**.

The diagram below illustrates the organization of matter.



**Worksheet**

1. Is doubling the temperature on the Celsius scale equivalent to doubling the temperature on the Kelvin scale? If not, which doubling of temperature is the larger increase? Explain.

2. Give an example of each of the following terms.

   a) homogeneous mixture
   b) heterogeneous mixture
   c) compound
   d) element
   e) physical change
   f) chemical change

3. Perform each of the following conversions.

   a) $8.43\ cm$ to millimeters.
   b) $2.41 \times 10^2\ cm$ to meters.
   c) $294.5\ nm$ to centimeters.
   d) $1.445 \times 10^4\ m$ to kilometers.
   e) $235.3\ m$ to millimeters.
   f) $903.3\ nm$ to micrometers.

4. Convert the following Celsius temperatures to Kelvin.

   a) the temperature of someone with a fever, $39.2℃$
   b) a cold wintery day, $-25℃$
   c) the lowest possible temperature, $-273℃$
   d) the melting point of sodium chloride, $801℃$

5. Convert the following Kelvin temperatures to Celsius.

   a) the temperature that is the same value in both Celsius and Fahrenheit, $233\ K$
   b) the boiling point of helium, $4\ K$
   c) the temperature at which many chemical quantities are determined, $298\ K$
   d) the melting point of tungsten, $3680\ K$

6. Diamonds are measured in carats, and $1\ carat = 0.200\ g$. The density of diamond is $3.51\ g/cm^3$.

   a) What is the volume of a 5.0 carat diamond?
   b) What is the mass, in carats, of a diamond with a volume of $2.8\ mL$?

7. Classify each of the following as a mixture or a pure substance.

   a) water
   b) blood
   c) the oceans
   d) iron
   e) brass
   f) uranium
   g) wine
   h) table salt