The Physical Properties And Physical Changes of Substances

A. Definitions In Science

1. Science is the observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena. We gather information about our surrounding through the use of our senses: sight, smell, hearing, taste, and touch.

   Over hundreds of years, people have developed tools that enhance our senses and allow us to gather information that would otherwise be impossible. Information usually takes one of two forms:

   QUALITATIVE information is **NON-NUMERICAL** information **(Descriptions)**

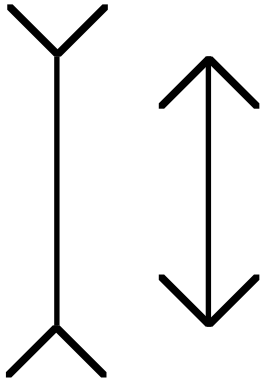
   QUANTITATIVE information is **NUMERICAL** information **(Measurements)**

   In Chemistry, you must be able to collect information and describe substances in many different ways. To ensure that we are using a common vocabulary, some important terms must be defined:

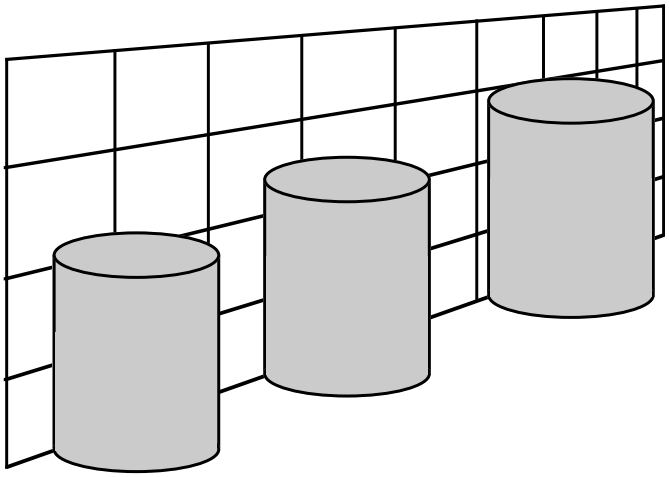
   - An **OBSERVATION** is qualitative information collected though the direct use of our senses.
   - An **INTERPRETATION** (or "inference") is an attempt to put meaning into an observation.

     Sometimes our interpretations of what we observe is biased by our expectations and prior knowledge.

Do you see a young lady or an old hag?



Which of the two lines is longer?



Which of the cylinders is the largest?

It is possible that two people may not observe the same thing. For this reason, scientists insist that observations be repeated several times by more than one person.

- A **DESCRIPTION** is a list of the properties of something.
- **DATA** is quantitative information which is experimentally determined or obtained from references.
- An **EXPERIMENT** is a test or a procedure that is carried out in order to discover a result.
- A **HYPOTHESIS** is a **SINGLE, UNPROVEN** assumption or idea which attempts to explain why nature behaves in a specific manner. when put forward, hypotheses are tentative but, if they survive testing, eventually gain general acceptance.
- A **THEORY** is a set of hypothesis that ties together a large number of observations of the real world into a logically consistent and understandable pattern. In other words, a theory is a **TESTED, REFINED,** and **EXPANDED** explanation of why nature behaves in a given way.

OBSERVATIONS → HYPOTHESIS → THEORY

Scientific Method

- A **LAW** is a broad generalization or summary statement which describes a large amount of experimental evidence stating how nature behaves when a particular situation occurs.

2. The following are general characteristics of **HYPOTHESES:**

- Hypotheses are normally single assumptions.
- Hypotheses are narrow in their scope of explanation.
- When originally proposed, hypotheses are tentative (being based on very incomplete evidence) but may become generally accepted after more complete testing.

e.g. **HYPOTHESES OF GASES:**

(i) All gases are made up of tiny, fast moving particles.

(ii) The tiny particles of a gas transfer some of their energy when they collide with other particles or with the container.

(iii) The tiny particles in a gas act like miniature billiard balls and the entire system undergoes no net change in energy when particles collide.

3. The following are general characteristics of **THEORIES:**

- Theories are composed of one or more underlying hypotheses.
- Theories are broad in scope and may have subtle implications which are not foreseen when they are proposed because they provide explanations for entire "fields" of related behaviour.
- Theories are sometimes called models because they often provide a concrete way to examine, predict, and test the workings of nature.
- Theories must be "falsifiable"; that is, they must make testable predictions about the behaviour of the system under NEW conditions.

e.g. **KINETIC THEORY OF GASES**

Gases behave the way they do because they are made up of point-like particles which are constantly moving, colliding, and exchanging energy.

4. The following are general characteristics of **LAWS:**

- Laws summarize the results of many experiments or observations and state what will happen when a specific situation occurs.
- Laws do not try to explain why something occurs.
- Laws are not "proven theories". Laws are often stated before any theory exists to explain why the law is true.

e.g. **BOYLE'S LAW** states that if the temperature is unchanged, the greater the pressure applied to a sample of gas, the smaller its volume.

CHARLES' LAW states that if the applied pressure is unchanged, the greater the temperature of a sample of gas, the greater its volume.

B. The Physical Properties of Matter

1. **CHEMISTRY** is the study of matter and its interactions.

> **MATTER** is defined as anything that has **mass and occupies space**. (Matter is what makes up everything other than energy.)

Hence, chemistry may be better described as the science concerned with the properties, composition, and behaviour of matter.

2. **SUBSTANCES** are things that have a unique and identifiable set of properties. A **PHYSICAL PROPERTY** of a substance is a property that can be found without creating a new substance.

e.g. Density, colour, hardness, and melting point

A **CHEMICAL PROPERTY** is the ability of a substance to undergo a chemical reaction and change into new substances, either by itself or with other substances.

e.g. Hydrogen gas can burn in air to produce water.

3. Physical properties can be either intensive or extensive.

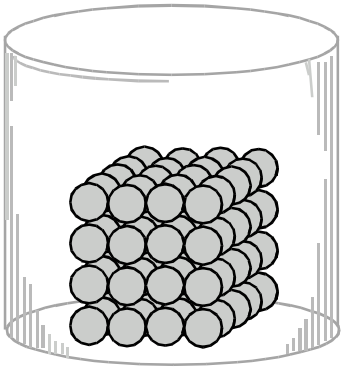
> An **INTENSIVE PROPERTY** is a physical property that does not depend on how much of the substance is present. (e.g. density, melting temperature)
>
> An **EXTENSIVE PROPERTY** is a physical property that does depend on the amount of substance present. (e.g. mass and volume)

Intensive properties can be used to identify a substance while extensive properties cannot be used to identify substances.

4. Matter can exist in three common states or **"PHASES"**: solid, liquid, and gas. The three common phases of mater each have a unique set of properties which allow a given substance to be classified.

(a) **SOLIDS**

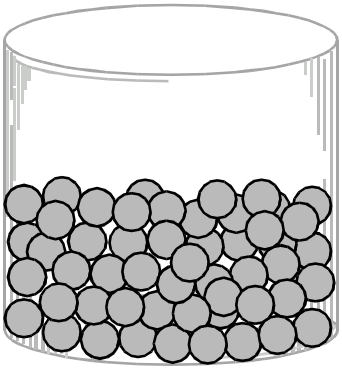
Solids are rigid and **DO NOT** readily change their shape. Solids experience very small changes in volume (expand) when heated or subjected to pressure.



In a solid, the particles are packed closely together into a given volume. The particles are highly organized and rigid which requires the particles to be in direct contact with each other. In general solids are **NOT** compressible.

(b) **LIQUIDS**

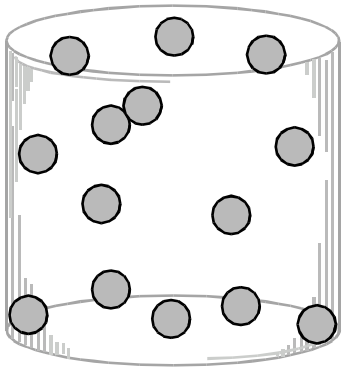
Liquids conform to the shape of their container and experience only slight changes in volume when heated or subjected to pressure



In a liquid, the particles remain in close contact with each other but have enough room to slide past one another easily and prevent an organized packing. Because the particles of a liquid are in close contact, they are also **NOT** compressible.

(c) **GASES**

Gases conform to the shape of their container but unlike solids or liquids they occupy the entire volume of the container. Gases experience **drastic changes in volume** when heated or subjected to pressure.



In a gas, the particles are widely separated and only contact each other during collisions. Most of the volume of a gas is **EMPTY SPACE**. Because the large separation of particles can be decreased, **gases are compressible**.

5. Some other physical properties of matter include:

HARDNESS	the ability of a solid to resist abrasion or scratching.
MALLEABILITY	the ability to be rolled or hammered into thin sheets.
DUCTILITY	the ability to be stretched or drawn into wires.
LUSTRE	the manner in which a solid surface reflects light. Lustres can vary from metallic to admantine (diamond-like), glassy, oily, pearly, silky, or dull.
VISCOSITY	the resistance of fluid to flow (thickness).
DIFFUSION	the mixing of fluids (gases and liquids) as a result of random motion within the fluid.
VAPOUR	the gaseous material formed by the evaporation of a substance which boils above room temperature.
VAPOUR PRESSURE (VP)	the pressure created by the vapour evaporating from a liquid.
BOILING POINT (BP)	the temperature at which a liquid changes state to a gas.
MELTING POINT (MP)	the temperature at which a solid changes state to a liquid.

C. The Classification of Matter

1. The physical properties of a substance can be used to classify or organize the substances into a number of categories. Recall the following terms:

   (a) **ELEMENT** is a substance which cannot be separated into simpler substances as a result of any chemical process.

   e.g. silver metal, hydrogen gas, copper metal

   (b) **ATOM** is the smallest possible unit of an element which retains the properties of the element.

   e.g. silver (Ag), hydrogen (H), copper (Cu)

   (c) **MOLECULE** is a group of two or more atoms joined together by chemical bonds.

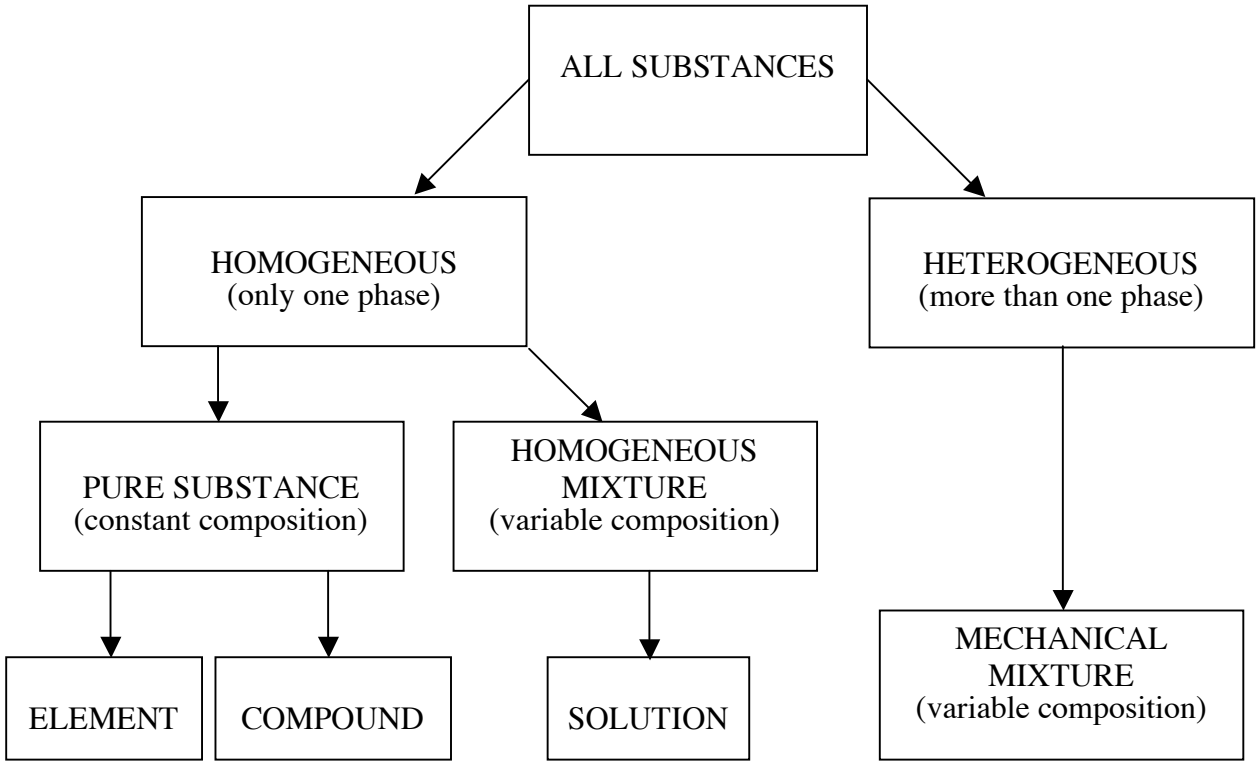
   e.g. water (H_2O), ethanol (CH_3CH_2OH), sodium carbonate (Na_2CO_3)

   (d) **ION** is an atom or molecule which possesses an electrical charge (positive or negative).

   e.g. sodium ion (Na^+), chloride ion (Cl^-), nitrate ion (NO_3^-), calcium ion (Ca^{2+})

   (e) **PARTICLE** is the general term used to describe a small bit of matter such as an atom, molecule, or ion.

2. Substances can be classified according to the following flowchart.



A **HOMOGENEOUS** substance is a substance consisting of only one phase.

e.g. air, water, salt water, a piece of iron

A **HETEROGENEOUS** substance is a substance consisting of more than one phase.

e.g. pencil, gravel, human being

A **PURE SUBSTANCE** is a substance that is homogeneous and has an unchangeable composition.

e.g. sugar, water, copper, iron

A **MIXTURE** is a system made up of two or more substances with variable composition.

e.g. salt dissolved in water, sugar in coffee

A **MECHANICAL MIXTURE** is a heterogeneous mixture of two or more substances.

e.g. gravel, sand and iron filings, a pencil

A **SOLUTION** is a homogenous mixture of two or more substances. There are several different types of solutions:

TYPE OF SOLUTION	EXAMPLE
gas—in—gas	air (oxygen, nitrogen, etc.)
gas—in—liquid	soda pop
liquid—in—liquid	water and alcohol
solid—in—liquid	salt water
solid—in—solid	alloys (metals melted together)

For a solution, the **solvent** is the component of the solution in greater quantity while the **solute** is the component in smaller quantity.

ELEMENTS are substances that cannot be separated into simpler substances by chemical processes.

e.g. substances in the periodic table — H, Pb, C, O, Ag …

COMPOUNDS are substances composed of two more types of atoms but only one type of molecule is present.

e.g. NaCl, H_2O, $C_6H_{12}O_6$

PURE SUBSTANCE = unchanging physical properties

HOMOGENEOUS MIXTURE = changeable composition but each particular composition has unchanging, uniform physical properties.

HETEROGENEOUS MIXTURE = each component present has different physical properties regardless of composition.

D. The Physical Separation of Substances

1. All the methods however, take advantage of **differences in the physical properties** of the substances involved.

MIXTURE	METHOD	WHEN TO USE METHOD
SOLID in SOLID	Hand separation	Large chunks present among other solids
	Gravity separation	The density of the desired solids is much different from the density of the other solids.
	Solvent extraction	One solid preferentially dissolves in a particular solvent
	Chromatography	The solids are coloured, present in small amounts and are soluble in some solvent or mixture of solvents
SOLID in LIQUID	Hand separation	A few large pieces of solid are present in the liquid
	Gravity separation	Solid particles are present in a **SMALL** amount of liquid
	Filtration	Solid particles are present in **LARGE** amount of liquid
	Evaporation	The solid is wanted and the liquid is not
	Distillation	The liquid is wanted; the solid may or may not be wanted
	Solvent extraction	An immiscible added solvent preferentially dissolves at least one but not all of the solids present
	Recrystallization	One dissolved solid is much less soluble than the others present (if any); the liquid is not wanted
	Chromatography	Small amounts of more than one coloured solid are present; the liquid present is not wanted
LIQUID in LIQUID	Distillation	Two or more liquids are present and have different boiling temperatures
	Solvent extraction	An immiscible added solvent preferentially dissolves at least one but not all of the liquids present

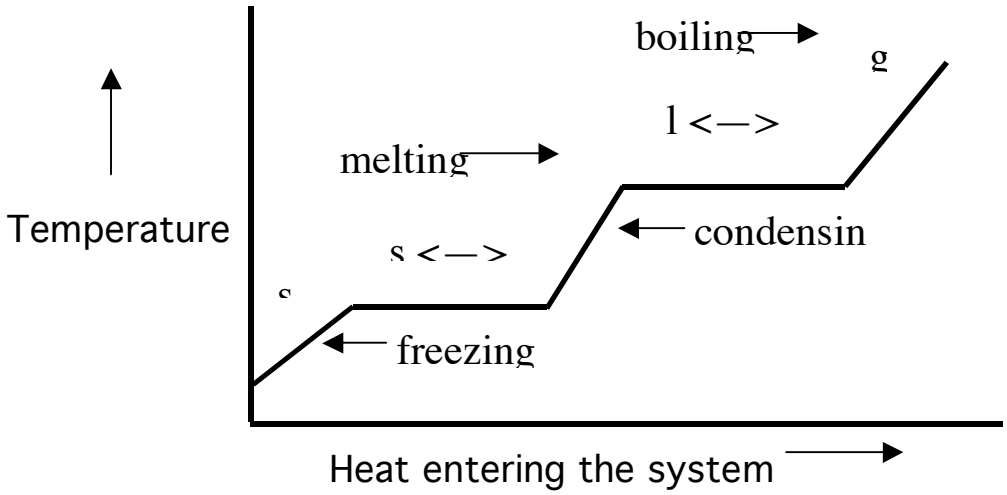
E. Phase Changes

1. Substances can undergo two kinds of changes, chemical or physical. Chemical changes produce a set of chemicals which is different from the set of chemicals which existed before the change. A physical change does not change the set of chemicals involved.

> A **CHEMICAL CHANGE** is a change in which **new substances** are formed.
>
> A **PHYSICAL CHANGE** is change in the phase of a substance, such that **no new substances** are formed.

Chemical changes are frequently accompanied by physical changes. For example, hydrogen gas and oxygen gas react to form liquid water

2. In general, continued heating of a solid produces the following temperature behaviour.



Notice that the temperature does not change during a phase change such as melting and boiling.

A. **MELTING TEMPERATURE** is the temperature at which a solid changes into the liquid phase.

B. **FREEZING TEMPERATURE** is the temperature at which a liquid changes into the solid phase. At the **MELTING/FREEZING** temperature the solid and liquid phases co-exist.

C. **BOILING TEMPERATURE** is the temperature at which a liquid changes into the gas phase.

D. **CONDENSATION TEMPERATURE** is the temperature at which a gas changes into the liquid phase. At the **BOILING/CONDENSING** temperature the liquid and gas phases co-exist.

As time goes on, heat is constantly entering the substance represented in the above graph.

On the sloping portions of the graph, all the heat is used to warm the substance so the temperature rises.

On the level portions of the graph, the substance contains so much heat energy that it cannot absorb more heat and stay in the same phase. The added heat is used, for example, to break up the solid and allow a liquid to form. All the heat is used to change phase so the temperature does not change and the graph levels off.

3. Kinetic energy (KE) = the energy that molecules possess when in motion.

   i. Rotational = molecule rotates around one of its axes.

   ii. Vibrational = bond lengths and angles change.

   iii. Translational = molecule travels in straight lines.

4. When a solid is heated, absorbed energy causes an increase in rotational and vibrational energy. Molecules oscillate back and forth and collide overcoming the force of attraction holding the molecules in a solid phase and the solid melts.

   As the liquid is heated, molecules increase in translational energy and move faster. Eventually, when enough translational energy is gained, molecules pull away from each to become a gas.