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IACPE No 19, Jalan Bilal Mahmood 80100 Johor Bahru Malaysia	Applied Chemistry CERTIFIED PROCESS TECHNICAN TRAINING MODULE	Great Job with a Great Future

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INTRODUCTION

Scope

This module introduces and then consolidates basic chemistry principles and promotes awareness of chemistry concepts for students needing a broad base for further vocational studies. It provides a foundation in chemistry principles, which will enable students to solve chemistry, scientific and associated technical principles. The material will provide applications and chemistry principles necessary for advancement onto a range of technical profiles. It is widely recognized that a students' ability to use chemistry is a key element in determining subsequent success.

Chemistry is the science that deals with the composition of matter. Understanding chemistry is fundamental to the operation of a chemical plant. It explains the changes that occur when chemical substances are changed into other chemical substances. This process is called a reaction. By its nature, a typical chemical plant uses chemical raw chemical materials to produce a final chemical product using various types of pre-planned reactions. Thus, having a good understanding of basic chemistry is important to performing your job safely, and it will help you understand the chemical operations you are aiding.

There are tables and figures that assist in making these chemistry calculations from the various reference sources. All the important parameters use in the guideline are explained in the definition section which help the reader more understand the meaning of the parameters or the term used.

In theory section, it will explain about atomic, elements, chemical equation, chemical calculations, solution characteristic, fuels, and hydrocarbons.Theory is introduced by a brief outline of essential theory, definitions, formulae, laws and procedures.

General Design Consideration

Chemistry deals with the composition, structure and properties of matter. These aspects can be best described and understood in terms of basic constituents of matter: atoms and molecules. That is why chemistry is called the science of atoms and molecules.

Chemistry is the branch of science that studies the composition, properties and interaction of matter. Chemists are interested in knowing how chemical transformations occur. Chemistry plays a central role in science and is often intertwined with other branches of science like physics, biology, geology etc. Chemistry also plays an important role in daily life.

Chemical industries manufacturing fertilizers, alkalis, acids, salts, dyes, polymers, drugs, soaps, detergents, metals, alloys and other inorganic and organic chemicals, including new materials, contribute in a big way to the national economy. Chemistry plays an important role in meeting human needs for food, health care products and other materials aimed at improving the quality of life. This is exemplified by the large-scale production of a variety of fertilizers, improved varieties of pesticides and insecticides. Similarly, many life saving drugs such as cisplatin and taxol, are effective in cancer therapy and AZT (Azidothymidine) used for helping AIDS victims, have been isolated from plant and animal sources or prepared by synthetic methods.

Matter, Substances and solutions

There are three main states of matter: *solid*, *liquid*, and *gas*. A solid has its own volume and shape. A liquid has its own volume but takes the shape of the vessel it is in. A gas fills the vessel it is in - it takes up the vessels volume and shape. (A powder takes the shape of the vessel it is in, but the individual grains have their own shape). Solid materials differ from one another in size or shape (e.g. steel plate, steel rod, steel wire, and steel wool), and in what they are made of.

In solids, these particles are held very close to each other in an orderly fashion and there is not much freedom of movement. In liquids, the particles are close to each other but they can move around. However, in gases, the particles are far apart as compared to those present in solid or liquid states and their movement is easy and fast (see figure 1).

i. Solids have definite volume and definite shape.

ii. Liquids have definite volume but not the definite shape. They take the shape of the container in which they are placed.

iii. Gases have neither definite volume nor definite shape. They completely occupy the container in which they are placed.

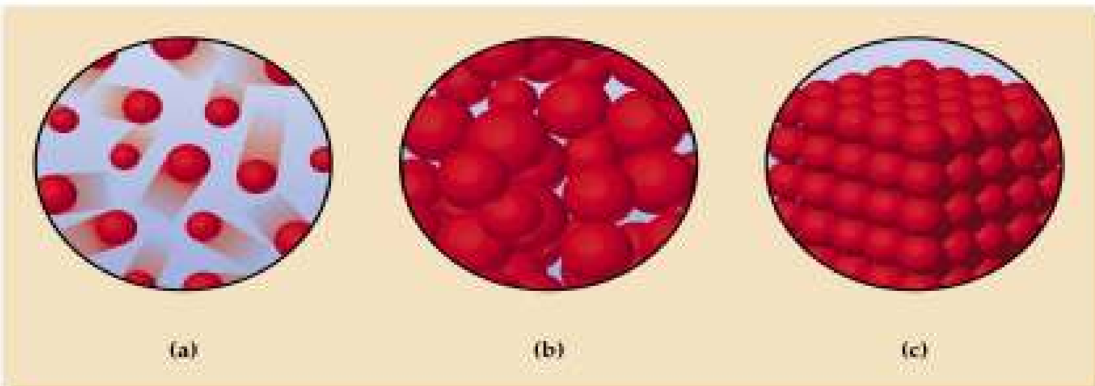


Figure 1: Particle of a. Gas, b. Liquid, and c. solid

Table 1: Different properties of states

Gases	Liquids	Solids
Variable shape and volume	Variable shape, fixed volume	Fixed shape and volume
May expand or compress	May flow, not compressible	Non-compressible crystalline solids
Low densities	High density	High density
Mix to form homogeneous mixtures	Mix if soluble	Do not mix by diffusion

At the macroscopic or bulk level, matter can be classified as mixtures or pure substances. These can be further sub-divided as shown in Figure 1.

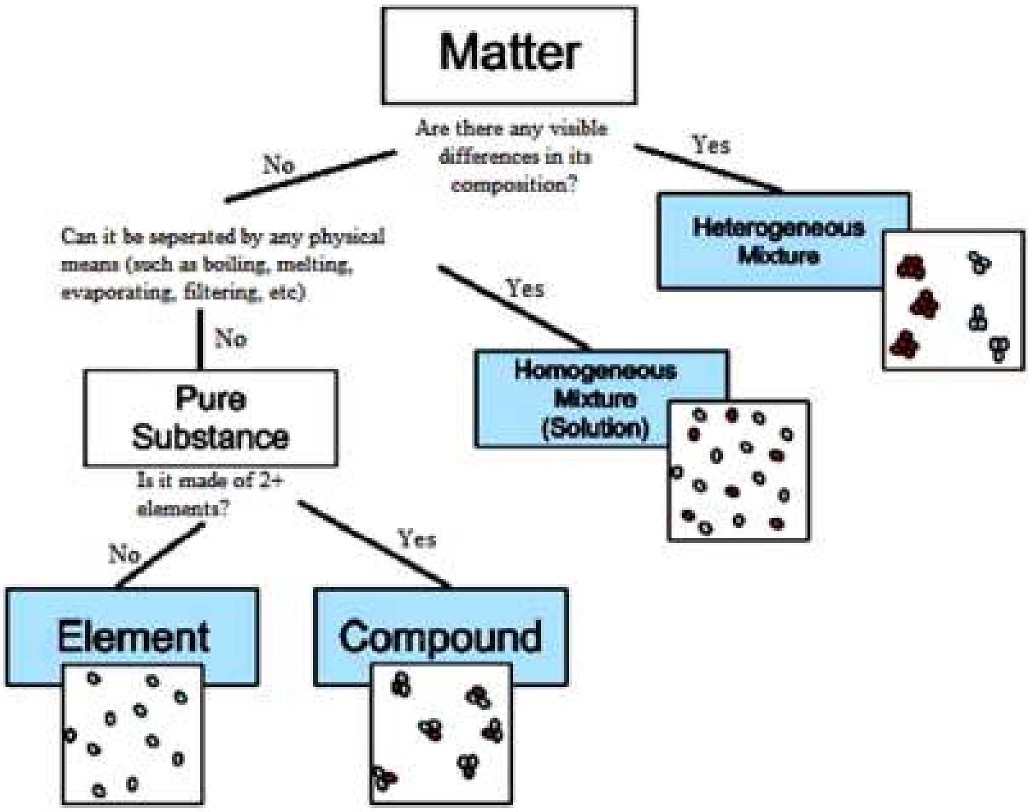


Figure 2: Classification of matter

There are two main types of basic material: homogeneous and heterogeneous. The former appears uniform under an optical microscope, the latter not. The latter are mixtures of the former. Basic materials can be made from other basic materials. In a homogeneous mixture, the components completely mix with each other and its composition is uniform throughout. Sugar solution, and air are thus, the examples of homogeneous mixtures. In contrast to this, in heterogeneous mixtures, the composition is not uniform throughout and sometimes the different components can be observed. For example, the mixtures of salt and sugar, grains and pulses along with some dirt (often stone) pieces,

Homogeneous basic materials can be divided into substances and solutions. A solution is a combination of substances in varying proportions. The principal component [the one that gives the solution its state (solid, liquid, or gas), or, if more than one component does this, the one that is in the larger amount] is called the solvent; minor components are called solutes.

Chemists separate components of solutions by distillation, crystallization, solvent extraction, chromatography, and other methods. A homogeneous basic material is a substance if it cannot be separated into components that can be recombined in varying proportions as for a solution.

Substances may be pure or impure. Impure substances contain small quantities of other substances, either mixed with them or dissolved in them. Pure substances melt and boil at a constant temperature, impure substances generally do not. Substances can be distinguished from one another by their state at room temperature and atmospheric pressure (solid, liquid, or gas), colour, density, melting point, boiling point, solubility in different solvents, action on other substances, and other properties.

Substances can be divided into elements and compounds on the basis of the chemical changes they are involved in. Compounds decompose into other substances, elements do not. Likewise, compounds can be made by combination of other substances, elements cannot. Compounds ultimately decompose into, and can be made from, elements. Some elements exist as more than one substance (this is over and above any change in substance with change of state, as discussed above for mercury). For example, carbon exists as graphite, diamond, buckminsterfullerene, etc. This phenomenon is called allotropy, and the different substances are called allotropes.

When two or more atoms of different elements combine, the molecule of a compound is obtained. The examples of some compounds are water, ammonia, carbon dioxide, sugar etc.

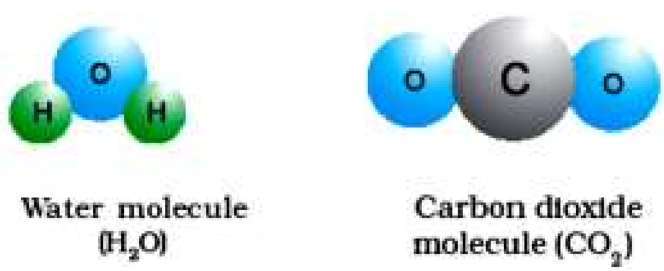
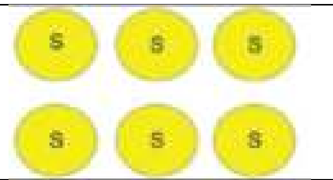
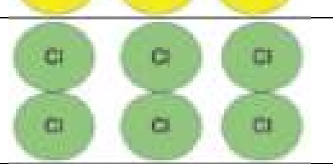
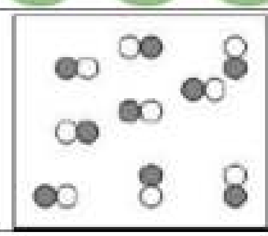
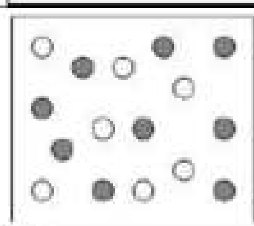
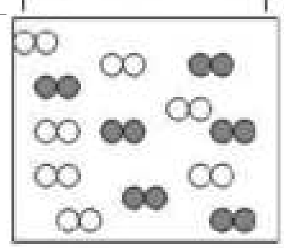


Figure 3: A depiction of molecules of water and carbon dioxide

Table 2: Different of matter

Pure substance (element)		Matter with only one type of atom is calledan element.
Pure substance (element)		Although the chlorine atoms are bonded inpairs, since there is only one type of atom, this is an element.
Pure substance (compound)		When two or more elements are bonded together, a compoundis produced.
Mixture		When two or morepure substances (in this case, two elements) are combined, but not bonded together, a mixture is produced.
Mixture		When two or more pure substances are combined, but not bonded together, a mixture is produced

Every substance has unique or characteristic properties. These properties can be classified into two categories – physical properties and chemical properties. Physical properties are those properties which can be measured or observed without changing the identity or the composition of the substance. Some examples of physical properties are colour, odour, melting point, boiling point, density etc. The measurement or observation of chemical properties require a chemical change to occur. The examples of chemical properties are characteristic reactions of different substances; these include acidity or basicity, combustibility etc.

Phase Transition

The term phase transition is most commonly used to describe transitions between solid, liquid and gaseous states of matter, and, in rare cases, plasma. A phase of a thermodynamic system and the states of matter have uniform physical properties. During a phase transition of a given medium certain properties of the medium change, often discontinuously, as a result of the change of some external condition, such as temperature, pressure, or others.

These three states of matter are interconvertible by changing the conditions of temperature and pressure.

$$\text{Solid} \underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}} \text{liquid} \underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}} \text{Gas}$$

On heating a solid usually changes to a liquid and the liquid on further heating changes to the gaseous (or vapour) state. In the reverse process, a gas on cooling liquefies to the liquid and the liquid on further cooling freezes to the solid.

- Vaporization — Liquid to gas transition
- Melting — Solid to liquid transition
- Condensation — gas to liquid transition
- Freezing — liquid to solid transition
- Sublimation — solid to gas transition
- Deposition — gas to solid transition

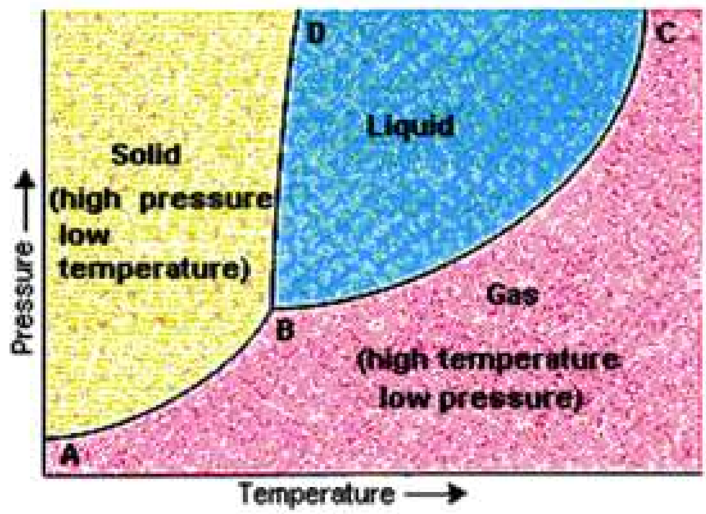


Figure 4: Phase diagram

The figure below shows an example of a phase diagram, which summarizes the effect of temperature and pressure on a substance in a closed container. Every point in this diagram represents a possible combination of temperature and pressure for the system. The diagram is divided into three areas, which represent the solid, liquid, and gaseous states of the substance. The best way to remember which area corresponds to each of these states is to remember the conditions of temperature and pressure that are most likely to be associated with a solid, a liquid, and a gas. Low temperatures and high pressures favor the formation of a solid. Gases, on the other hand, are most likely to be found at high temperatures and low pressures. Liquids lie between these extremes.

The points along the line connecting points *A* and *B* in the phase diagram in the figure above represent all combinations of temperature and pressure at which the solid is in equilibrium with the gas. At these temperatures and pressures, the rate at which the solid sublimes to form a gas is equal to the rate at which the gas condenses to form a solid.

Along *AB* line:

rate at which solid sublimes to form a gas = rate at which gas condenses to form a solid

The solid line between points *B* and *C* is identical to the plot of temperature dependence of the vapor pressure of the liquid. It contains all of the combinations of temperature and pressure at which the liquid boils. At every point along this line, the liquid boils to form a gas and the gas condenses to form a liquid at the same rate.

Along *BC* line:

rate at which liquid boils to form a gas = rate at which gas condenses to form a liquid

The solid line between points *B* and *D* contains the combinations of temperature and pressure at which the solid and liquid are in equilibrium. At every point along this line, the solid melts at the same rate at which the liquid freezes.

Along *BD* line:

rate at which solid melts to form a liquid = rate at which liquid freezes to form a solid

Point *B* in this phase diagram represents the only combination of temperature and pressure at which a pure substance can exist simultaneously as a solid, a liquid, and a gas. It is therefore called the triple point of the substance, and it represents the only point in the phase diagram in which all three states are in equilibrium. Point *C* is the critical point of the substance, which is the highest temperature and pressure at which a gas and a liquid can coexist at equilibrium.

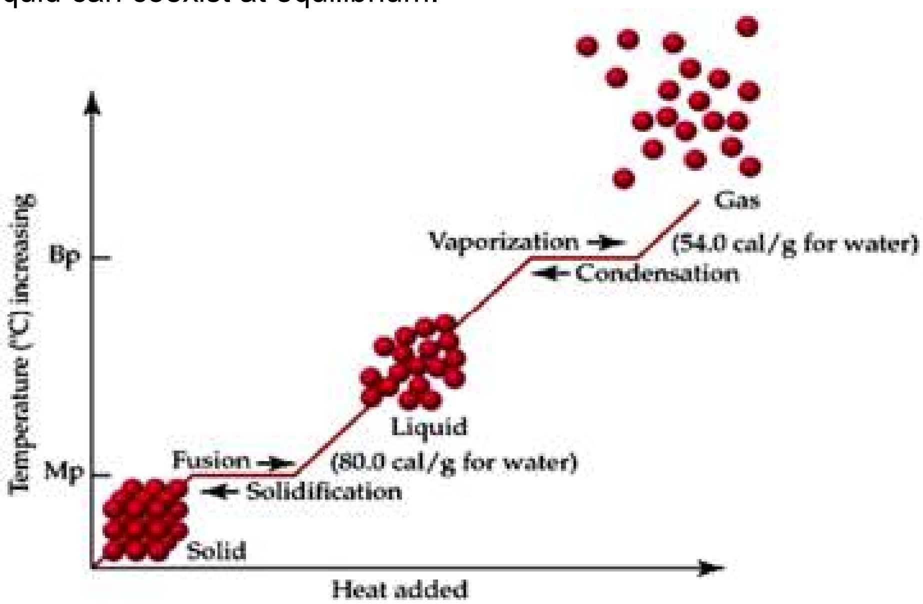


Figure 5: Phase diagram of mater

This graph shows the phase diagram of mater. At the beginning we have solid. solid gain heat in the interval that is the melting point of it. It is only solid in the 1st region, temperature of the mass does not change because its state is changing in this interval. Gained heat is spent on breaking the bonds of molecules. 2nd region includes both liquid and solid. After melting process completed, in the 3rd region there is only liquid and temperature of water starts to increase. When the temperature of the liquidin boiling point, it starts to boil and evaporation of it speeds up. In region 4, mass exists in two state, liquid and gas. After completion of evaporation, all liquid converted to the gas and in region 5, it is only gas.

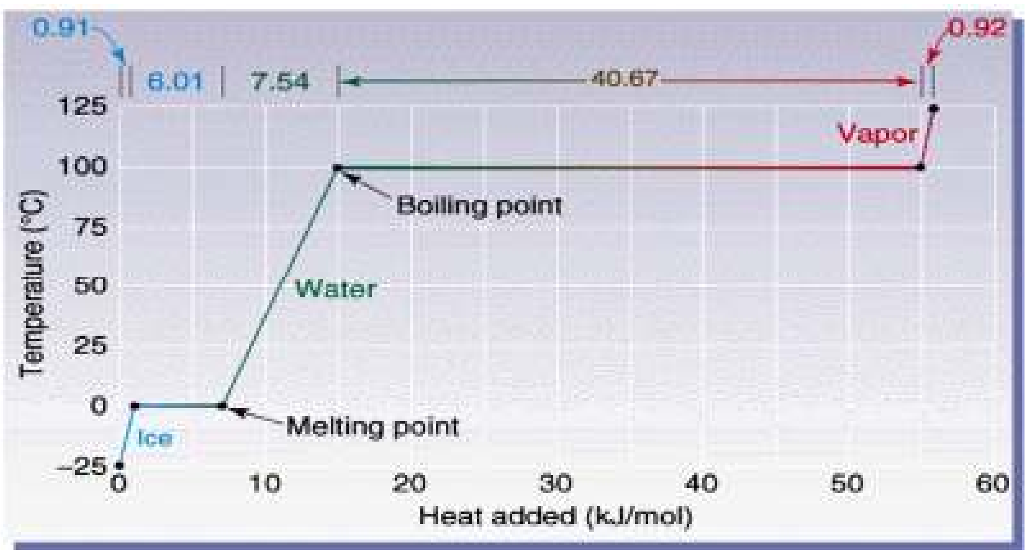
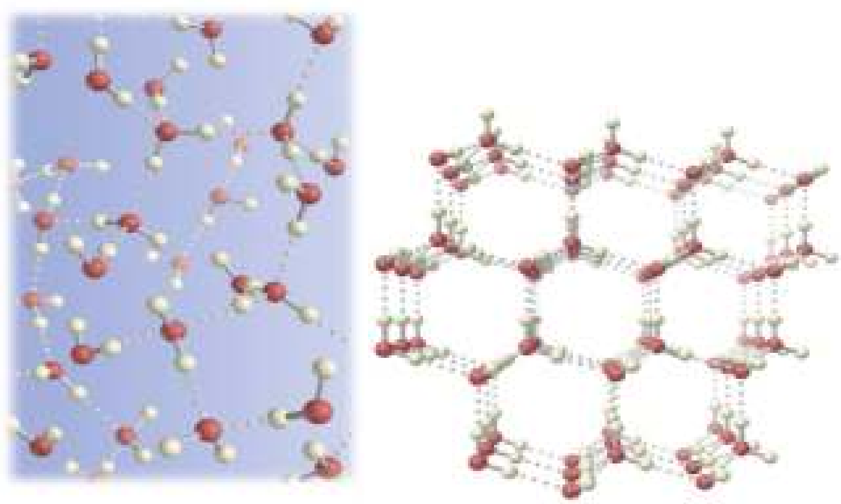


Figure 6: Water phase diagram

This graph shows the phase diagram of water. At the beginning we have ice at -20 ºC. Ice gain heat in the interval of points A and B, and its temperature becomes 0 ºC that is the melting point of it. We have only ice in the 1st region. As you can see between the points B and C, temperature of the mass does not change, because its state is changing in this interval. Gained heat is spent on t breaking the bonds of molecules. 2nd region includes both water and ice. After melting process completed, in the 3rd region there is only water and temperature of water starts to increase. When the temperature of the water becomes 100 ºC, it starts to boil and evaporation of it speeds up. In region 4 our mass exists in two state, water and steam. After completion of evaporation, all water converted to the steam and in region 5 we have only vapor of water.

Water

Water is the most abundant compound on Earth's surface. In nature, water exists in the liquid, solid, and gaseous states. It is in dynamic equilibrium between the liquid and gas states at 0 degrees Celsius and 1 atm of pressure. At room temperature (approximately 25 degrees Celsius), it is a tasteless, odorless, and colorless liquid. Many substances dissolve in water, and it is commonly referred to as the universal solvent. Water (H_2O) is a polarinorganic compound that is at room temperature a tasteless and odorless liquid, nearly colorless with a hint of blue.



Liquid water Solid water

Figure 7: Molecule of water in different phase

Below are the properties of water

- colorless, odorless, tasteless, liquid at ordinary temperatures
- only inorganic compound occurring naturally as a liquid
- composes ~65% of mass of living organisms
- excellent solvent for many things
- abnormally high boiling and melting point
- ice is less dense than water (it floats)

Water Purification

Unpurified water has become one of the major problems all over the world not only in big cities, but also in rural areas as well. Today, this unpurified water is the major reason behinds lots of diseases both in human beings and animals. To get rid of this severe problem, several ways have been adopted to purify the water. At present, water is available in different types.

- Hard water -- is that type of water, in which mineral contents like Ca^{+2}, Mg^{+2}, Fe^{+3} and other minerals as well as chlorides are present in abundance and create hardness in water. This hard water does not provide good cleaning results due to having no ability of mixing with soap.
- Soft water -- When we remove these Ca^{+2}, Mg^{+2}, Fe^{+3} ions from water by means of ion exchange or precipitation method, the obtained water is called soft water that give efficient cleaning response after mixing with soap.
- Softened water -- metal cations in hard water are replaced by Na^{+}.
- Deionized water -- When we remove not only microscopic impurities that are present in water, but also mineral salts of calcium, sodium, copper, iron, bromide and chloride as well by means of ionization process, the resulted water is called as deionized water. The ionization process involves the separation of salt ions by means of positive and negative electrodes in electrically charged solution. Cations are replaced by H+ and anions are replaced by OH^{-}

Gas

Gas is a state of matter that has no fixed shape and no fixed volume. Gases have lower density than other states of matter, such as solids and liquids. There is a great deal of empty space between particles, which have a lot of kinetic energy. The particles move very fast and collide into one another, causing them to diffuse, or spread out, until they are evenly distributed throughout the volume of the container. Gases have three characteristic properties: (1) they are easy to compress, (2) they expand to fill their containers, and (3) they occupy far more space than the liquids or solids from which they form. A gas mixture would contain a variety of pure gases much like the air.

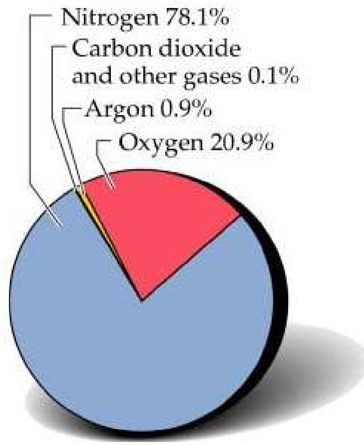


Figure 8: Composition of Dry Air

Properties of Gases

- Gases have an indefinite shape
- Gases expand to fill their containers uniformly
- Gases are compressible
- Gases have low densities
  - air 0.0013 g/mL
  - water 1.00 g/mL
  - iron 7.9 g/mL
- Gases diffuse uniformly throughout their containers to form homogeneous mixtures.
- A gas exerts a pressure

Kinetic molecular theory

The basics of the Kinetic Molecular Theory of Gases (KMT) should be understood. This model is used to describe the behavior of gases. More specifically, it is used to explain macroscopic properties of a gas, such as pressure and temperature, in terms of its microscopic components, such as atoms. Like the ideal gas law, this theory was developed in reference to ideal gases, although it can be applied reasonably well to real gases.

In order to apply the kinetic model of gases, assumptions are made:

- Collection of particles in constant motion.

- No attraction or repulsions between particle; collisions like billiard ball collisions.
- A lot of space between the particles compared to the size of the particles themselves.
- The speed that the particles move increases with increasing temperature.

Unlike solids and liquids, there is much empty space between the particles in a gas. Applying a force pushes the particles into the empty space, compressing the gas (see figure 9). Pressure is caused by the collisions of gas particles with the surface of the container. At high pressures, the molecules of a gas are crowded closer together, and the amount of empty space between the molecules is reduced. At these higher pressures, the volume of the gas molecules themselves becomes appreciable relative to the total volume occupied by the gas. The gas therefore becomes less compressible at these high pressures, and although its volume continues to decrease with increasing pressure, this decrease is not *proportional.*

Unlike gases, there is little empty space between the particles in a liquid. Liquids are not very compressible when we apply pressure. Some compression does occur, but it is many orders of magnitude less than the compression in a gas subject to the same pressure (see figure 9).

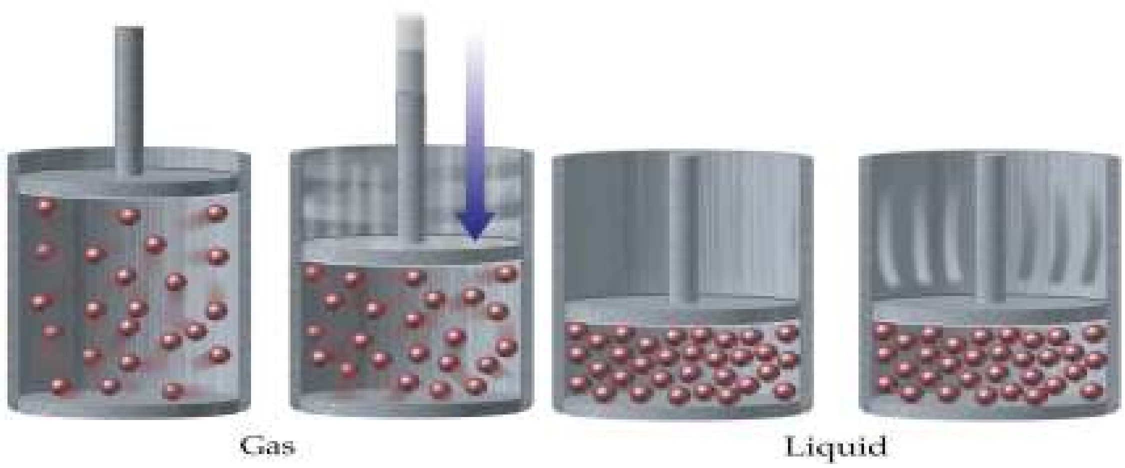


Figure 9: Applying a force pushes in gas and liquid particles

Atmospheric pressure, sometimes also called barometric pressure, is the pressure exerted by the weight of air in the atmosphere of Earth (or that of another planet). In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point. Low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location.

The standard atmosphere (symbol: atm) is a unit of pressure defined as 101325 Pa (1.01325 bar), equivalent to 760 mmHg (torr), 29.92 inHg and 14.696 psi. Variations about these values are quite small; for example, the highest and lowest sea-level pressures ever recorded are 32.01 inches (in the middle of Siberia) and 25.90 inches (in a typhoon in the South Pacific). The small variations in pressure that do exist largely determine the wind and storm patterns of Earth. Near Earth's surface the pressure decreases with height at a rate of about 3.5 millibars for every 30 metres (100 feet)

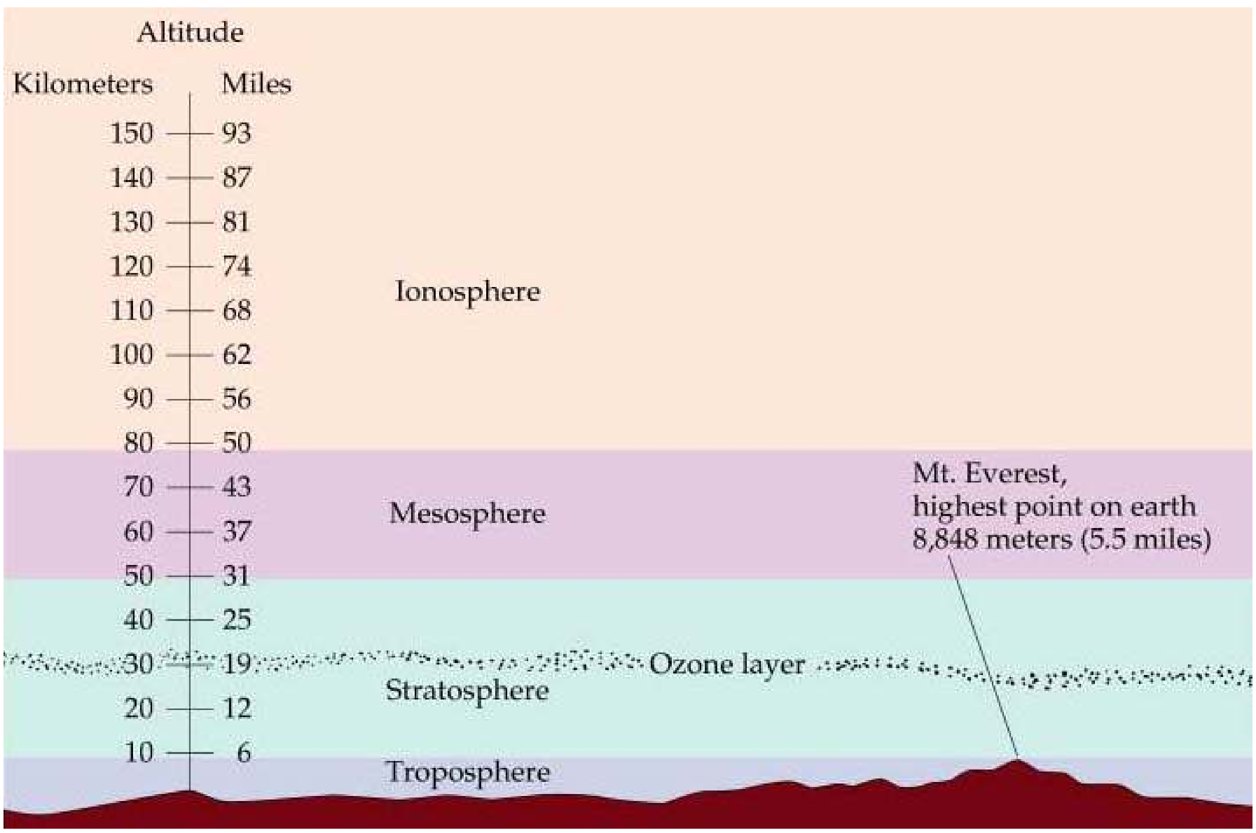


Figure 10: Relationship of altitude to atmospheric pressure

A barometer is a scientific instrument used in meteorology to measure atmospheric pressure. Pressure tendency can forecast short term changes in the weather.

A mercury barometer has a glass tube closed at one end with an open mercury-filled reservoir at the base. The weight of the mercury creates a vacuum in the top of the tube known as Torricellian vacuum. Mercury in the tube adjusts until the weight of the mercury column balances the atmospheric force exerted on the reservoir. High atmospheric pressure places more force on the reservoir, forcing mercury higher in the column. Low pressure allows the mercury to drop to a lower level in the column by lowering the force placed on the reservoir. Since higher temperature levels around the instrument will reduce the density of the mercury, the scale for reading the height of the mercury is adjusted to compensate for this effect. The tube has to be at least as long as the amount dipping in the mercury + head space + the maximum length of the column.

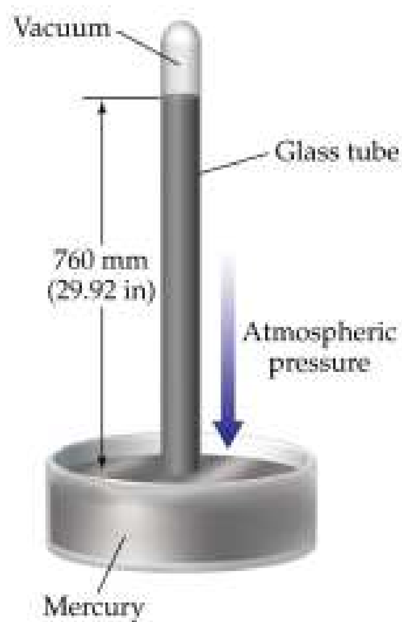


Figure 11: A mercury barometer

DEFINITIONS

Chemical changes: changes that occur when one substance is turned into another substance; different types of molecules are present at the beginning and end of the change.

Chemistry: the study and practice of making basic materials and determining their character.

Coefficient: a small whole number that appears in front of a formula in a balanced chemical equation

Compound: a substance that can be made from or decomposed into elements.

Element: a substance that does not undergo chemical decomposition into, and cannot be made by chemical combination of, other substances.

Equilibrium: A state that occurs when the rate of forward reaction is equal to the rate of the reverse reaction.

Hydrocarbon: an organic substance consisting of only hydrogen and carbon

Indicator: a substance that changes color at a specific pH and is used to indicate the pH of the solution

Ionic bond: A bond between ions resulting from the transfer of electrons from one of the bonding atoms to the other and the resulting electrostatic attraction between the ions.

Ionic compound: a positively charged particle (typically a metal) bonded to a negatively charged particle (typically a nonmetal) held together by electrostatic attraction

Material: a particular kind of matter, especially one that is intended for some use.

Matter: that which occupies space and has mass.

Mixture: a combination of two or more elements or compounds which have not reacted to bond together; each part in the mixture retains its own properties

Periodic table: a tabular arrangement of the chemical elements according to atomic number.

Physical changes: changes that do not alter the identity of a substance, the same types of molecules are present at the beginning and end of the change.

Products: materials present at the end of a reaction, shown on the right of the arrow in a chemical equation

Reactants: the starting materials in a reaction, shown left of the arrow in a chemical equation

Solute: minor component of a solution.

Solution: a homogeneous basic material that can be separated into components that can be recombined in varying proportions starting with 0% of one.

Solvent: principal component of a solution.

Substance: a homogeneous basic material that cannot be separated (by the methods chemists usually employ) into components that can be recombined in varying proportions as for a solution.

Titration: the lab process in which a known concentration of base (or acid) is added to a solution of acid (or base) of unknown concentration

NOMENCLATURE

% mass	Percentage of mass, %
[acid]	the molar concentration of an acidic solution
[base]	the molar concentration of a basic solution
$[H^+]$	the molar concentration of hydrogen
$[OH^-]$	the molar concentration of hydroxide
a	amount of H^+ in acid
b	amount of OH^- in base
K_f	the freezing point constant, kg °C/mol
K_w	the equilibrium constant for water at 25° C (unitless)
m	molality, moles/kg
M	molarity, moles/L
Ma	the molarity of the acid
Mb	the molarity of the base
n	mole, moles
pH	the log of the molar concentration of the hydrogen
pKa	the equilibrium dissociation constant for an acid
Va	the volume of the acid
Vb	the volume of the base
X	mole fraction
ΔT	temperature depression, °C