PHYSICAL SCIENCE.

<u>UNIT ONE</u>: MATTER AND KINETIC THEORY

MATTER

Matter is anything that has ***mass*** and occupies ***a volume***. ***Mass*** is the **quantity of matter** in an object. The SI unit of mass is the ***kilogram (kg).*** ***Volume*** is the **amount of space** occupied by an object. The SI unit of volume is the ***cubic metre (m^3).***

STATES OF MATTER

There are four states of matter and these are *solid*, *liquid*, *gas and plasma*.

- Solid is a state of matter in which an object naturally retains its shape.
- Liquid is a state of matter in which matter can be poured like water
- Gas is a state of matter in which an object is neither solid, liquid nor intermediate.
- Plasma is the state of matter that consists of an overall charge-neutral mix of electrons, ions and neutral atoms. The sun and stars are plasma.

Matter is made up of very small particles called ***molecules***. A *molecule* is the smallest particle of matter that can exist independently at normal temperatures and pressures. Molecules are held together by ***electrostatic forces called intermolecular forces*** *or* ***van der waals forces.*** The larger the size of the molecules and the closer they are together, the greater are the sizes of the intermolecular forces.

Molecules are made from very tiny particles called ***atoms.*** An *atom* is the smallest particle of matter that can take part in a chemical combination. Atoms join together to form molecules. The forces that hold atoms together are called **interatomic forces** or **chemical bonds.** Interatomic forces are stronger than intermolecular forces.

KINETIC THEORY OF MATTER/ MOLECULAR THEORY OF MATTER

It states that 'matter is made up of small particles that are constantly in motion.' These particles are the molecules or atoms. The word '*kinetic*' means '*moving*' in Greek.

In solids, particles are held together by strong electrostatic forces and are arranged in a regular pattern. The particles in solids vibrate in their fixed positions but the vibrations are too small to be seen without the use of a microscope.

Some of the properties of solids are;

- Have fixed shape because the particles are tightly packed together.
- Have definite volume and shape.
- Have smallest degree of compressibility.
- Have generally higher densities.
- Can be seen and felt.
- Have low expansion rates.
- Are mostly hard.

In liquids, particles are slightly further apart in an irregular pattern. The forces that hold particles of liquids are weaker than those in solids. Particles in liquids vibrate and slide over each other.

Some of the properties of liquids include;

- They flow because their particles slide over each other.
- Have fixed volume.
- Have no fixed shape but take the shape of the container.
- Have medium compressibility.
- Have medium expansion rates.
- Have medium densities.

In gases, particles are very further apart. The distance between molecules is large compared to the size of the molecules. Gas particles have almost no attraction for one another. Gas particles move in straight lines in all directions, colliding frequently with one another and with the walls of the container resulting into change in direction and speed. No **energy** (*ability to do work*) is lost by the collision of a gas molecule with another gas molecule or with the walls of the container. All collisions are perfectly elastic. The average kinetic energy (energy of movement) for gas molecules is the same for all gases at the same temperature. The zigzag motion of particles is called ***Brownian motion*** or ***random motion***.

Some of the properties of gases are;

- They can flow.
- Have no fixed volume and they completely fill in any container into which they are put.
- Have no fixed shape.

- Are easily compressible.
- Have high expansion rates.
- Have very low densities.

Liquids and Gases are referred to as ***fluids*** because they both flow.

MOLECULAR MOTION AND GAS PRESSURE

The continuous collisions of gas molecules with one another and with the walls of the container cause a pressure on the walls of the container. Gas pressure on any object is produced by a steady bombardment on the object by gas molecules. Pressure results from the sum of the forces from the collisions on the container walls. When the temperature of a gas is increased, the molecules move faster and hit the walls more often and harder, causing the pressure to increase.

TEMPERATURE AND MOLECULAR MOTION

When a solid is heated, the particles gain energy and vibrate more and more vigorously. Eventually they may break away from the solid structure and become free to move around. When this happens, the solid has turned into liquid through the process called **melting.** When a liquid is heated, some particles gain enough energy to break away from other particles. The particles which escape from the body of the liquid become a gas in a process known as **evaporation.** The rapid evaporation is called **boiling.** Thus, when the temperature of an object is raised, the average speed of the random movement of its individual atoms or molecules is also raised.

TEMPERATURE

Temperature is defined as a measure of relative hotness of objects or how hot or cold something is.

Temperature scale is the range of numbers for measuring the level of hotness. There are different temperature scales such as *Celsius/Centigrade*, Fahrenheit and the *Absolute (Kelvin) Scale.*

- The SI unit of temperature on the Celsius Scale is the *degree Celsius (^oC).* This scale is based on the melting/freezing point of pure ice which is 0 ^{o}C (32F) and the boiling point of pure water which is 100 ^{o}C (212F) under standard atmospheric pressure of 101325 pascals (Pa)
- *Absolute temperature* is the temperature that is based on the average kinetic energy of particles.

The SI unit of temperature on the Absolute Scale (Thermodynamic Scale) is the ***Kelvin (K).***

At 0 K, particles have their lowest kinetic energy possible. Zero kelvin is also referred to as absolute zero.
When converting degrees Celsius into kelvins, add 273 to the number of degrees while when converting kelvins into degrees Celsius, subtract 273 from the number of kelvins. For example 25^oC = (25+273) K = 298K and 546K = (546-273) ^oC $=273^oC$.

SOME EVIDENCES OF MOLECULAR MOTION

- *Exchange of atoms which takes place during a chemical reaction implies movement.* If the reacting particles were not moving, they would not come into contact with each other and no reaction would be possible.

- *Diffusion:* This is the spreading of particles from a region of higher concentration to a region of low concentration. It takes place in all fluids (liquids and gases) since there spaces between the individual particles through which other particles can pass.
- Diffusion is faster in gases than in liquids due to large spaces between the gaseous particles. Lighter gases diffuse faster than heavier ones. For instance, ammonia gas diffuses faster than hydrogen chloride gas since ammonia gas is lighter than hydrogen chloride gas. Diffusion can also be accelerated by raising temperature since particles move faster.

- *Brownian motion* as observed under a microscope.

PRESSURE

Pressure is the *force exerted per unit area*. The SI unit of pressure is the ***pascal (Pa***). It can also be expressed in newtons/squaremetre (N/m^2), millimeters of mercury (mmHg), atmospheres (atm), Torricellis (torr) or mill bars (mbar).
1 Pa = 1 N/m^2.
Mathematically***, Pressure = Force /Area***
The SI unit of area is the square metre (m^2). 1 m^2 = 10000 cm^2.

FACTORS THAT AFFECT PRESSURE OF SOLIDS.

- *Size of force*; with constant area, the larger the force, the larger the pressure.

- *Area on which the force acts*; with constant force, the greater the area over which the force acts, the smaller is the pressure. For instance, caterpillar tracks on some heavy vehicles are designed to reduce the pressure which the vehicle exerts on the ground, by increasing the area over which the weight acts

Pressure is therefore directly proportional to the force and inversely proportional to the area on which the force acts.

LIQUID PRESSURE

This is the *pressure that a liquid exerts on any surface*. When a liquid is immersed in a fluid, the fluid exerts a pressure on all sides of the object. In a fluid, pressure acts equally in all directions.

FACTORS THAT AFFECT PRESSURE IN A LIQUID COLUMN

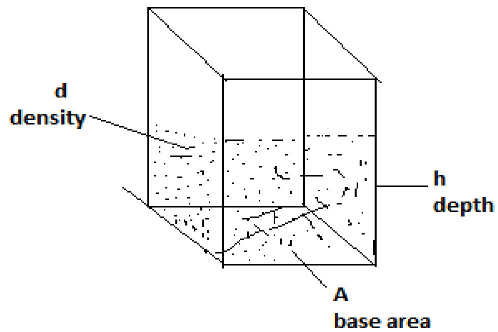
These are;

- *Depth/height of the liquid column*; the greater the depth, the greater the pressure. The deeper you go down a liquid column, the larger is the weight that exert pressure on any level.
- *Density of the liquid*; the larger the density of the liquid, the larger is the pressure at any level. For instance, given two identical glass tubes one filled with mercury (density $13.6g/cm^3$) and the other filled with water (density $1g/cm^3$) to the same height, pressure at the bottom of mercury will be greater than that of water.

Pressure of a liquid column is given by the formula, **$p = hdg$,** where **p** is the pressure in pascals **(Pa), d** is the density in kilogram/cubic metre (**kg/m^3)** and **g** is the gravitational field strength which is equivalent to 10N/kg. This formula is derived from the formula;

Pressure = Force/Area as follows;

Consider the column below of **cross-sectional area, (A) m^2, height, (h) m** and which contains a liquid of **volume, (V) and density, (d) kg/m^3.**



Volume of the liquid, V= *area of cross-section (**A**) **x** height (**h**) = **Ah***
Mass of the liquid, m = *Volume (**V**) **x** density (**d**) = **Vd = Ahd***
Weight of the liquid W = *Mass (**m**) **x** gravitational field strength (**g**) **= mg = Ahdg***
Pressure at the base of the column = *Weight of the liquid / Area of cross-section*

$$= W/A$$

$$= Ahdg/A$$

$$P = hdg$$

SOME USES OF LIQUID PRESSURE IN EVERYDAY LIFE.

- *Hydraulic Systems*
  Hydraulic machines (eg hydraulic brakes and jacks) make use of the following properties of liquids.
  - Liquids are almost incompressible
  - If a trapped liquid is put under pressure, the pressure is transmitted equally to all the parts of the liquid. The fluid in a hydraulic braking system transfers the force on the brake pedal to the brake cylinder. In a hydraulic jack the fluid transfers the force on the smaller piston to the larger piston. Hydraulic systems act as force multipliers since a small force applied on one end yields a larger force on the other.
- *Construction of dams.*
  Dams are constructed in such a way that the bottom is thicker than the top in order for it to withstand the lager water pressure at the bottom.
- *Water supply systems.*

Reservoirs for water supply or hydroelectric power stations are often made in mountainous regions. The lower the place supplied the greater the water pressure at it.

NOTE:

All gases exert pressure. The magnitude of the pressure is decided by the number of collisions per second of the molecules with the sides of the container.

FACTORS THAT AFFECT GAS PRESSURE

- *Number of molecules/Amount of gas*: The greater the number of molecules, the bigger is the pressure.

- *Volume of the container*: Decreasing the volume causes gas molecules to bump into sides and lid of a container more often thereby increasing the pressure. With constant number of molecules and at constant temperature, decreasing the volume increases the pressure as happens in syringes, bicycle pumps etc.

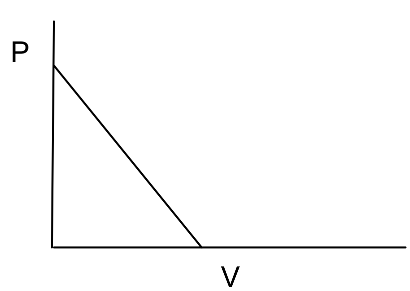
- *Temperature of the gas*: When temperature is raised molecules gain more kinetic energy and therefore they move faster hitting the walls more often and harder. With constant volume and constant number of molecules, increasing the temperature results into increase into pressure.

The interdependence of pressure, temperature and volume were investigated and their relationships together with the laws of mechanics form the basis of the kinetic theory of gases.

1. **BOYLE'S LAW OF GASES;**

   It states that *'For a constant amount of gas at constant temperature, pressure is inversely proportional to the volume'*. Mathematically **$P \alpha 1/V$.**

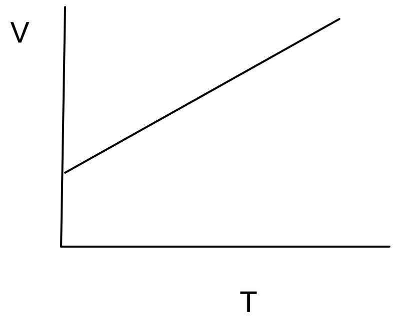
   Graphically,



2. **CHARLES' LAW OF GASES;**

It states that *'For a constant amount of gas at constant pressure, volume is directly proportional to the kelvin temperature'*. Mathematically, **VαT.**

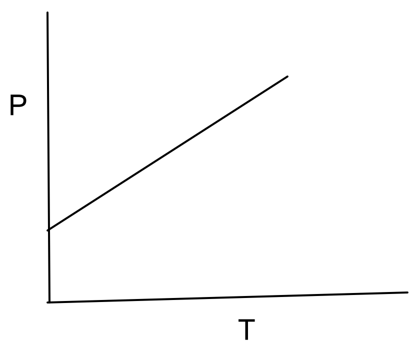
Graphically,



3. **PRESSURE LAW OF GASES;**

It states that *'For a constant amount of gas with constant volume, pressure is directly proportional to kelvin temperature'*. Mathematically, **PαT.**

Graphically,



The three laws can be combined mathematically into what is called the ideal gas equation; $\frac{PV}{T}$ **= constant.** The constant depends on the amount of gas involved.

The law can also be summarized by the following general gas equation;

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

where the suffix **1** represents the initial state and **2** the final state of the gas.

When only *Boyle's law* is involved, use; $P_1V_1 = P_2V_2$.

When only *Charles' law* is involved, use; $\frac{V_1}{T_1} = \frac{V_2}{T_2}$

When only *Pressure law* is involved, use; $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

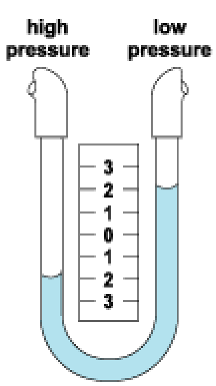
An **ideal gas** is a hypothetical gas whose pressure-volume-temperature behavior can be accounted for by the ideal gas equation.

ATMOSPHERIC PRESSURE

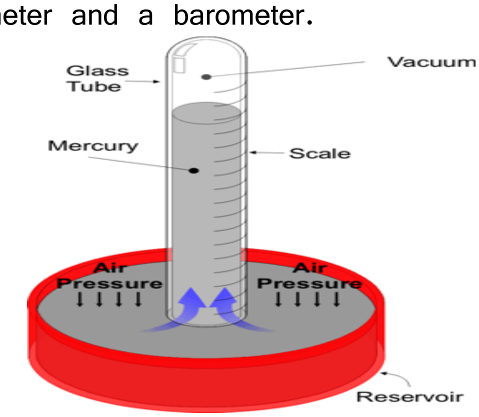
This is the *pressure that is exerted by the air in the atmosphere on any surface on the earth.* Air has weight which act on an area. The layer containing air around the earth which is roughly about 300 km from the earth's surface is called atmosphere. This means that a column of air about 300 km high acts on any surface on earth be it a liquid or a solid.

Atmospheric pressure can be measured by *a barometer or a manometer*. A manometer supports a height of about 10 m of water while a barometer holds a height of 0.76m of mercury (Hg). At sea level, *atmospheric pressure is about 100000 N/m*^{2} *= 100000 Pa = 760 mm Hg = 1 atmosphere.* Atmospheric pressure decreases with increase in height above sea level. 1 atmosphere of pressure is called the standard pressure and 0 ^{0}C is called the standard temperature.

Below are diagrams of a manometer and a barometer.



A U-tube manometer



A mercury barometer

MEASUREMENT OF PRESSURE FROM A GAS SUPPLY.

A manometer is used when measuring pressure of a gas supply. A manometer actually measures *pressure difference*. The height difference results from the extra pressure that the gas supply has in addition to atmospheric pressure. This extra pressure is called the **excess pressure.**

To find the actual pressure of the gas supply, the excess pressure is added to the atmospheric pressure. It can also be worked out directly by applying the formula p=hdg where p is the pressure in Pa, h is the height difference in m and g = 10 N/kg.

Some uses of air pressure:

- Siphoning of liquids
- Lifting of planes
- Used in tyres of cars
- Used in spray cans

USES OF THERMAL EXPANSION AND CONTRACTION OF SOLIDS.

All matter expands when heated and contract when cooled. To **expand** means *to take a bigger volume* while to **contract** means *to take a smaller volume*.
Gases expand more than liquids and liquids expand more than solids. Different solids expand by different amounts when heated equally. Metals expand more than non-metals. When different metals of identical dimensions are heated equally, they expand differently. For example, when bimetallic strip is heated, it bends towards the metal of low expansion rate. The metal that expands more contracts more too.
When an object is heated its volume increases, its mass remains constant while its density decreases.

Expansion of solids depends on;

- its length
- its temperature rise and
- the type of material.

Below are some of the uses of thermal expansion and contraction of solids;

- ***Removal of stuck glass tumblers and tightly screwed bottle covers***. Hot water is run over the outer tumbler so that it should expand before the inner tumbler. This facilitates the easy separation of the two. Similarly, when hot water is run over the bottle cover, it expands before the bottle does. This becomes easier to unscrew it.

- ***Shrink-fitting***: The metal to be fitted into a given hole is firstly dipped into very low temperatures such as liquid nitrogen (at $-196\ ^0C$) so that it should shrink (contract). It is then immediately slipped into the hole. On regaining normal temperature it gives a tight fit.

- ***Riveting of metal plates***: A white-hot rivet is placed in the rivet hole in between metal plates and its ends are hammered flat. On cooling, the rivet contracts and pulls the plates together. Riveting takes place in ship-building, car and bicycle manufacturing and other industries.

- ***Fire alarms***: Heat from the fire makes the bimetallic strip bend and complete the electrical circuit, thereby ringing the alarm bell.

- ***Motorway bridges are made in concrete sections with expansion gaps between the sections.*** The expansion gaps are filled with soft material such as rubber to stop chunks of rock from falling in.

- ***Tooth filling***: The filling material must have a thermal expansion approximately equal to that of the tooth to avoid cracking problems.

- ***Train wheels are fitted with steel tyres by heating the tyres***. This makes each tyre expand slightly so that it can be fitted on the wheel. Then, as the tyre cools, it contracts to make a very tight fit on the wheels.

- Railway tracks as designed to allow for thermal expansion. ***Gaps between rails*** are essential or else the tracks would buckle in hot weather.

- ***Telephone wires are loosely held*** in order to allow for contraction during cold weather.

- ***Thermostats*** control the temperature of some electrical appliances such as electric irons, refrigerators and ovens by the bending of the bimetallic strip which breaks and remakes the electric circuit.

PRACTICE QUESTIONS

1. State three evidences of the molecular motion in matter.

2. Describe the *kinetic theory* of
   - Solids
   - Liquids
   - Gases
3. What causes gas pressure?

4. Explain why the average molecular speed increases when temperature increases?

5. a. Convert the following into kelvins
   - *−100 °C*
   - *273 °C*

   b. Convert the following into degrees
   - *0 K*
   - *500 K*

6. How does each of the following work?
   - *A manometer*
   - *A mercury barometer*

7. Derive the formula for pressure exerted by a liquid column.

8. State at least two factors that affect pressure in solids, liquids and gases

9. Explain why pressure of a gas increases when
   - *amount of gas increases*
   - *volume of gas decreases*
   - *temperature of gas increases.*

10. Convert 1.2 atmospheres of pressure into
    - *pascals*
    - *mm Hg*

11. Write down any five *uses of thermal expansion and contraction of solids*

12. 375 cm^3 of gas M has a pressure of 87kPa. What will be its *volume* if the pressure is reduced to 85kPa?

13. A helium sample at 25°C has a volume of 1.82 l. If the pressure and amount of helium are unchanged, determine what the *volume* will be when the temperature is 50°C and 12°C?

14. A fixed mass of a certain gas has a volume of 76 cm^3 at 37°C and a pressure of 85kPa. Find the *volume* that the gas would occupy at stp (standard temperature and pressure)?

15. A 500 ml sample of a gas is at a pressure of 640 mm Hg. What must the *pressure* be, if the temperature is unchanged, at 800 ml and 350 ml?

16. A quantity of gas has a volume of 120 cm^3 and has a pressure of 298 K. What will be its *volume* at 360 K if the pressure is maintained constant?

17. A gas in a fixed container is at a pressure of 4 atmospheres (atm) and a temperature of 27^oC. What will the *pressure* be if it is heated to a temperature of 177^oC ?

18. What *temperature* in degrees Celsius must be reached to double the volume of a gas at constant pressure and moles of gas if the gas was at 55^oC originally?

19. Given 20.0 l of ammonia gas at 5^oC and 730 mm Hg pressure, calculate the volume at 50^oC and a pressure of 800 mm Hg.

20. To what *temperature* in ^oC must 10.0 l of nitrogen at 25^oC and 700 mm Hg be heated in order to have a volume of 15.0 l and a pressure of 760 mm Hg?

21. The volume of a gas filled balloon is 50.0 l at 20^oC and a pressure of 742 mm Hg. What *volume* will it occupy at stp (273 K and 760 mm Hg)?

22. Explain in terms of molecules
    - the process of evaporation
    - why the pressure of the air inside a car tyre increases when the car is driven at high speed.

23. A balloon contains 6 m^3 of helium at a pressure of 100 kPa. As the balloon rises through the atmosphere, the pressure falls and the balloon expands. Assuming that the temperature does not change, what is the *volume* of the balloon when the pressure has fallen to 50 kPa?

24. Some trapped air, of volume 4 m^3, has a pressure of 3 atmosptheres when its temperature is 27^oC. What will its *pressure* be if it is compressed into half the volume and heated to 127^oC?

25. The piston of a diesel engine has an effective area of 200 cm^2. What is the *pressure* of the gas in the cylinder when the total force exerted on the piston is 15 kN.

26. A 3.20 cm^3 air bubble forms in a deep lake at a depth where the temperature is 8^oC at a total pressure of 2.45 atm. The bubble rises to a depth where the temperature and pressure are 19^oC and 1.12 atm, respectively. Assuming the amount of air in the bubble has not changed, calculate its *new volume*.

27. Hydrogen gas is contained in a 360 cm^3 glass bulb at standard temperature (0oC) and pressure (1 atm). Calculate its *new pressure* if it is carefully transferred into a glass bulb of volume 340 cm^3 at 40^oC.

28. At 34^oC, a sample of a given gas occupies 250 cm^3. Find the *new volume* at 100^oC if the pressure remains constant.