TOPIC 2

THERMAL PHYSICS

THERMAL PHYSICS:

The branch of physics that study the temperature, heat energy and their relation to the matter.

Temperature:

It is the degree of hotness of an object and it can be measured by thermometer. Temperature can be express by Celsius (^oC), Fahrenheit (^oF) or K scale.

Heat:

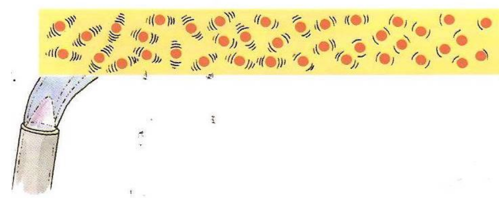
It is the energy which travels from high temperature to low temperature in a matter. It is also called thermal or internal energy. It is measured in joules (J).

MOLECULAR MODELS:

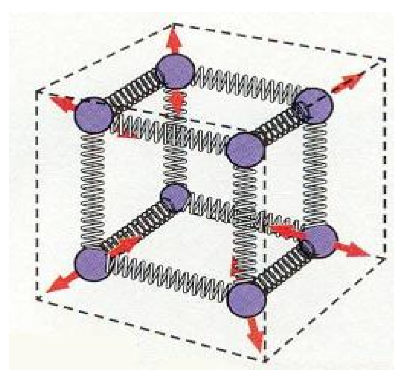
Matter is made up of atoms and molecules, which may only be seen by electronic microscope.

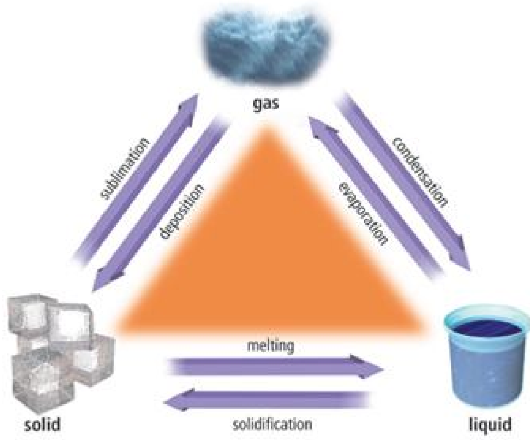
Kinetic Molecular Theory of Matter:

The kinetic molecular theory explains the forces between molecules and the energy that they possess. This theory has 3 basic assumptions.



1. Matter is made up of tiny small particles (atoms, molecules or ions). The measure of volume of matter is derived from the space in between the molecules and not the space the molecules contain themselves.
2. The molecules are in constant motion (vibration, rotation or translations). The motion of the molecules increases as they gain the kinetic energy which is proportional to the temperature of the matter.
3. Heavier particles move more slowly than the lighter ones at a given temperature.
   a. In solids the molecules are closely packed together. There is an attractive and repulsive force between them, very similar to spring. The molecule vibrates backward and forward about its fixed mean position. Solids keep the definite volume and shape.
   b. In liquids the molecules are slightly apart. They vibrate backward and forward as well as move rapidly over a short distance before they collide with each other. Molecules that gain sufficient energy evaporate





from liquid. Liquids have no definite shape but definite volume.

c. The molecules in gases are much farther apart. The molecules move around with very high speed in all directions and exert very little force on each other. Gases have no definite shape and size.

4. When the molecules collide with each other, or with the walls of a container, there is no loss of energy.

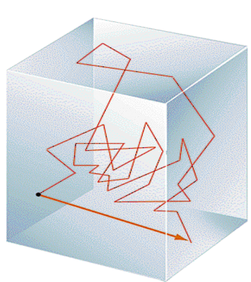
STATES OF MATTER:

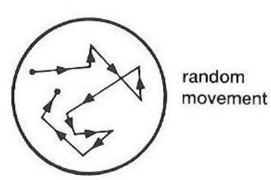
Objects that take up space and have mass are called **matter.** There are three states of matter that is solids, liquids and gases. The properties of the particles are:

Solids	**Liquids**	**Gases**
Fixed shape, size and volume	No fixed shape but fixed volume	No fixed shape, size or volume
vibrate about a fixed position	can flow; some movement randomly around each other	can move freely and at random at very high velocity in all space available
particles are closely bound	particles loosely bound	particles are free to move
strong attractive and repulsive force between them	weaker force of attraction	exert no force on each other
little expansion upon heating	slightly more expansion upon heating	large expansion upon heating
little or no compression on application of pressure	little or no compression on application of pressure	much more compression upon heating

Brownian motion:

Random movement of particle of liquids or gases is called Brownian motion. It was discovered by Scottish Botanist Robert Brown in 1827. He observed that the fine pollen grain on the surface of water are not stationary but moving about in a random motion. This random motion of pollen grains caused by much smaller, invisible faster moving water particles when they hit pollen grains from all direction. This motion is called Brownian motion after the scientist who observed this phenomenon for the first time.

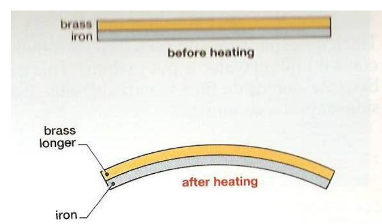




Evaporation, Boiling and Melting:

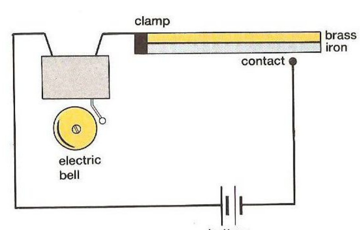
Evaporation	Boiling	Melting
Evaporation is the process of converting liquid into vapours.	Boiling is the process of converting liquid into vapours at the boiling point.	Melting is the process of converting solids into liquids
As a result of increasing the temperature of liquid the molecules start moving faster and gain enough energy to break the intermolecular bonding and escape from the surface.	As a result of increasing the temperature of liquid the molecules start moving faster and gain enough energy to break the intermolecular bonding and escape from the liquid.	As a result of increasing the temperature of solid the molecules start vibrating at faster rate and gain enough energy to weaken the intermolecular bonding.
It happens at any temperature.	It happens only at the boiling point of the liquid.	It happens only at melting point of the solid.
It happens at the liquid surface only.	It happens anywhere within the liquid.	It happens at the surface.
Average E_k decreases and therefore the temperature of liquid decreases	Average E_k stays the same and therefore the temperature of liquid does not increase	Average E_k stays the same while melting and therefore the temperature of solid does not increase
Bubbles not formed	Bubbles formed	No bubbles formed
The opposite of evaporation is condensation by cooling	The opposite of boiling is condensation by cooling	The opposite of melting is solidification or freezing by cooling

EXPANSION OF SOLIDS AND LIQUIDS:



All matter expands when heated because of the increase in the vibration of the molecules. Solids expand the least and liquid expand more than solid. Examples of expansion from daily life are:

1) Shrink fitting of axles into gears wheels by cooling the axels in liquid nitrogen at -196 ^{o}C (metal).
2) In kitchen tight metal lids can be opened from class jar by immersing the lid in hot water so that it expands (metal).
3) Expansion of mercury in thermometer when measuring temperature (liquid).
4) Water level rises behind the dam when the temperature of water increases due the heat from the sun (liquid).
5) Gap between the railways tracks due to expansion in summer (metal).
6) Bimetallic strips: Strips of iron and copper or brass. Copper expands more than the Iron. It is mostly used in fire alarm and thermostat (metal).



Linear expansion of solids:

The linear expansivity α of a substance is the increase in length of 1 meter for every 1^oC. For example steel: 0.000012 $/^oC$.

Expansion= linear expansivity × original length × change in temperature

or

$\Delta L = \alpha L_o \Delta\theta$

ΔL is change of length $(L- L_o)$

α is linear expansivity

$\Delta\theta$ is change of temperature in ^oC $(\theta-\theta_o)$

(Δ means the different of two values)

Volume expansion of solids:

If the expansion of all three dimensions of a material is considered then:

Volume expansion = cubical expansivity × original volume × change in temperature

or

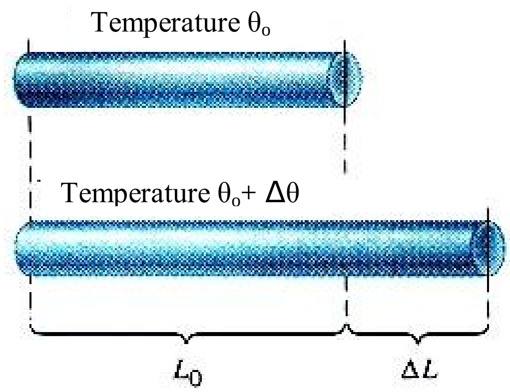
$\Delta V = \gamma V_o \Delta\theta$

ΔV is Change of Volume $(V-V_o)$

γ is Cubical expansivity

$\Delta\theta$ is Change of temperature $(\theta-\theta_o)$

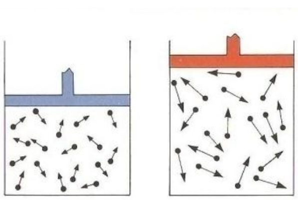
For solids $\gamma = 3\alpha$



Cubic Expansivities examples

Solid (copper) = 0.00005/ ^oC
Liquid (water) = 0.0002/ ^oC
Gas = 0.0037/ ^oC

TEMPERATURE, PRESSURE AND VOLUME OF GASES:



Unlike solids and liquids, a gas does not necessarily expand when heated. This is because the volume is depend upon the container and therefore when heated the collision of molecules with each other and with the walls of the container increase and therefore the pressure increase, it the volume kept constant.

The effect of pressure and temperature on gas:

1) Pressure of a gas is the force exerted by gas per unit area. It is the measurement of the number of collisions of molecules with the walls of the container.

2) The velocity and the number of collisions of these molecules increase with the increase of temperature that is increase in kinetic energy of molecules, if the volume of the gas kept constant.
3) Lowering the pressure decreases its temperature.

The Gas Laws:

Charles's law: volume – temperature relationship at constant pressure

The volume of fixed mass of gas is directly proportional to its temperature if the pressure is kept constant i.e.

Volume ∝ Temperature (at constant pressure)

$$V \propto T$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Pressure law: pressure-temperature relationship at constant volume

The pressure of the fixed mass of gas is directly proportional to its absolute temperature if the volume kept constant.

Pressure ∝ Temperature (at constant volume)

$$p \propto T$$

$$\frac{p}{T} = constant$$

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

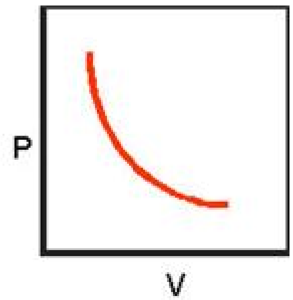
Boyle's law: pressure - volume relationship at constant temperature

The pressure of fixed mass of gas is inversely proportional to its volume if its temperature is kept constant.

$$p \propto \frac{1}{V}$$

$$pV = constant$$

$$p_1V_1 = p_2V_2$$



General gas law:

$$\frac{pV}{T} = \text{constant} \quad \text{or} \quad \frac{p_1 \times V_1}{T_1} = \frac{p_2 \times V_2}{T_2}$$

In all Gas laws the temperature must be used in kelvin scale.

Absolute zero:

The lowest possible temperature is called absolute zero. It is -273°C or 0 K. At absolute zero molecular motion of a substance is barely exists and it has no internal energy which is against the laws of physics.

T (in kelvin scale) = 273+θ (in Celsius scale)

In physics the kelvin temperature is expressed by ‘capital letter T’ and degree Celsius is expressed by Greek symbol theta θ.

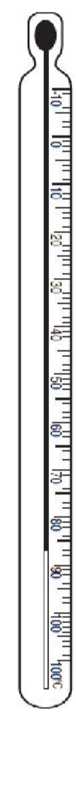
Expansion of water a special case:

The expansion of water is a special case. Unlike all matters the water contracts when its temperature increases from 0^oC to 4^oC. Water has a maximum density at 4^oC. At 0^oC when it freezes, a considerable volume expansion occurs and for every $100cm^3$ of water it becomes 109 cm^3 of ice. This is why ice floats on the surface of water.

MEASUREMENT OF TEMPERATURE:

Volume of liquid is a physical property which varies with temperature. This property of liquid may be used for the measurement of temperature. The daily life example is thermometer. Two common liquids that are used in thermometers are

- Mercury: It freezes at -39^oC and boils at 357^oC. It has low specific heat capacity and it expands uniformly when heated. It doesn’t stick to the glass.
- Alcohol: It freezes at -115^oC and boils at 78^oC therefore it is suitable for low range temperature. It is ideal for measuring atmospheric temperature. It expands uniformly when heated. It is colored and therefore better visible.

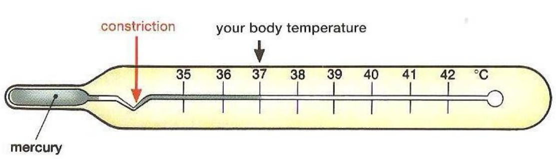


Liquid in glass thermometer:

<u>Fixed points in thermometer:</u>

It was marked zero for the temperature when ice freezes and marked 100 when water starts boiling. Then it was divided into 100 equal parts. It was invented by Swedish scientist and named it Celsius. Both temperatures are measured at normal pressure of 10^5 Pa (or N/m^2).

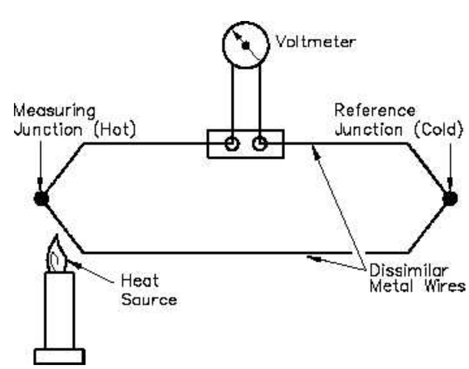
<u>Clinical Thermometer:</u>



It is a special thermometer with scale at both sides of normal body temperature. The special addition is the constriction that breaks the mercury and we read the temperature. Normal body temperature is 37^oC.

Thermocouple Thermometer:

A thermocouple consists of wires of two different materials e.g. copper and iron, joined together. When one junction is at a higher temperature than the other, an electric charge flows and produces a current reading on a sensitive meter which



depends on the temperature difference between the two junctions.

Thermocouples are used in industry to measure a wide range of temperatures from -250°C up to about 1500°C, especially rapidly changing ones and those of small objects.

Linear scale: A scale in which the divisions are uniformly spaced.

SPECIFIC HEAT CAPACITY:

The Specific heat capacity of a substance is the amount of heat required to raise the temperature by 1°C for the mass of 1 kg and is denoted by letter c. The unit of specific heat capacity is J/(kg °C).

Example of 1 kg of water and 1 kg of paraffin (kerosene) would receive same amount of heat energy for the same amount time but paraffin raises double the temperature. Hence by definition:

$$Specific\ heat\ capacity = \frac{total\ heat\ energy\ provided}{mass\ of\ substance \times change\ in\ temperature}$$

$$c = \frac{Q}{m \times \Delta\theta}$$

Where c is the specific heat capacity, Q is the amount of heat energy in joules, m is the mass of substance in grams or kilograms and $\Delta\theta$ is the change in temperature.

Specific heat capacity of water is very high compare to other substances. It is 4200J/(kg °C). It is useful in cooling car engines.

Thermal capacity:

The thermal capacity of a body is the quantity of heat needed to raise the temperature of whole body by 1°C.

Thermal capacity = mass × specific heat capacity

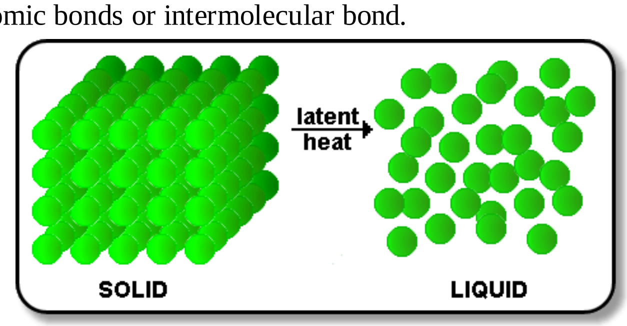
= m × c or

$$Thermal\ caparity = \frac{Q}{\Delta\theta}$$

Internal energy:

Internal Energy is the energy stored in a system at the molecular level that is its thermal energy. It is the kinetic energy of the atoms (or molecular) due to their random motion plus the binding energy or electric potential energy that holds the atoms (or molecular) together in terms of atomic bonds or intermolecular bond.

LATENT HEAT OF FUSION:

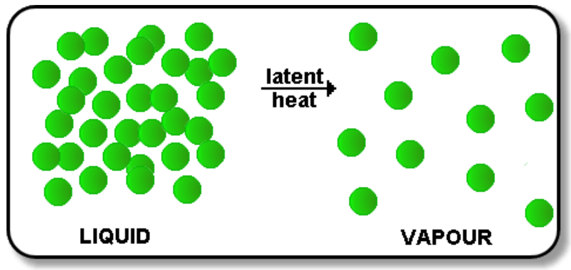


When a solid substance changes its state from the solid to the liquid, energy must be supplied in order to overcome the molecular attractions between the particles of the solid. This energy must be supplied externally, normally as heat, and does not change the temperature. We call this energy latent heat (the word "latent" means "invisible"). It is the energy released or absorbed during a change of state without increasing the temperature.

Specific latent heat of fusion:

"The specific latent heat of fusion (L_f) of a substance is the amount of heat energy (Q) required to convert unit mass (m) of the solid into the liquid without a change in temperature." Mathematically

$$L_f = \frac{Q}{m}$$



LATENT HEAT OF VAPORIZATION:

The change of state from liquid to vapour at constant temperature also requires the input of energy, called the latent heat of vaporization. This implies that while a liquid undergoes a change to the vapour state at the boiling point, the temperature of the liquid will not rise beyond the temperature of the boiling point.

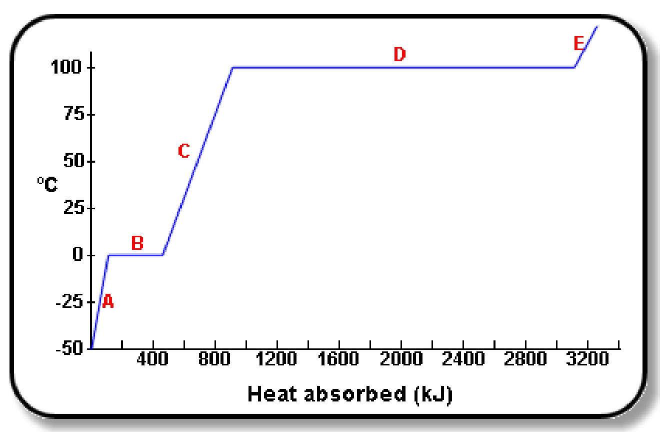
The latent heat of evaporation is the energy required to overcome the molecular forces of attraction between the particles of a liquid in order to break their intermolecular bonds, and bring them to the vapour state, where such attractions are minimal.

Specific latent heat of vaporization:

'The specific latent heat of vaporization (L_v) is the amount of heat energy (Q) required to convert unit mass (m) of a liquid into the vapour without a change in temperature.' Mathematically

$$L_v = \frac{Q}{m}$$

Heating/cooling curves:



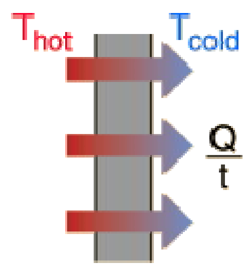
The diagram on the left shows the uptake of heat energy by 1 kg of water, as it passes from ice at -50 ºC to steam at temperatures above 100 ºC, affects the temperature of the sample.

A: Rise in temperature as ice absorbs heat.
B: Absorption of latent heat of fusion.
C: Rise in temperature as liquid water absorbs heat.
D: Water boils and absorbs latent heat of vaporization.

E: Steam absorbs heat and thus increases its temperature.

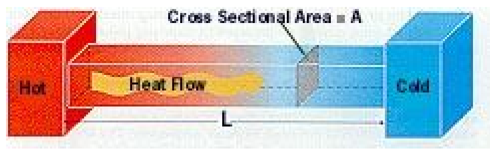
The above is an example of a heating curve. One could reverse the process, and obtain a cooling curve. The flat portions of such curves indicate the phase changes.

TRANSFER OF THERMAL ENERGY OR HEAT ENERGY:



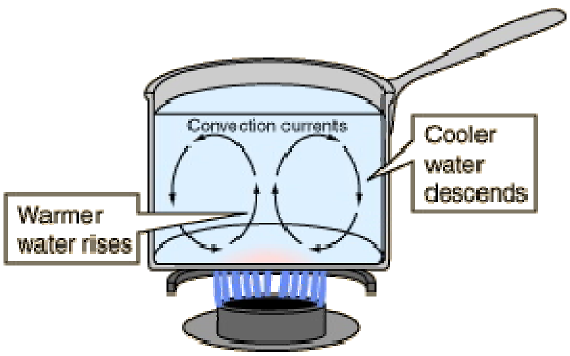
The transfer of heat energy normally occurs from higher temperature to lower temperature. Heat transfer changes the internal energy of both systems involved. There are three ways that heat can transfer in matter. That is conduction, convection and radiation.

Conduction:



Conduction always occurs in solids. It is the heat transfer by means of faster molecular motion within a material without any shift of the material as a whole. If one end of a metal rod is at a higher temperature, then energy will be transferred towards the colder end because the higher speed particles will collide with the slower ones with a net transfer of energy to the slower ones. All metal substances are good conductors.

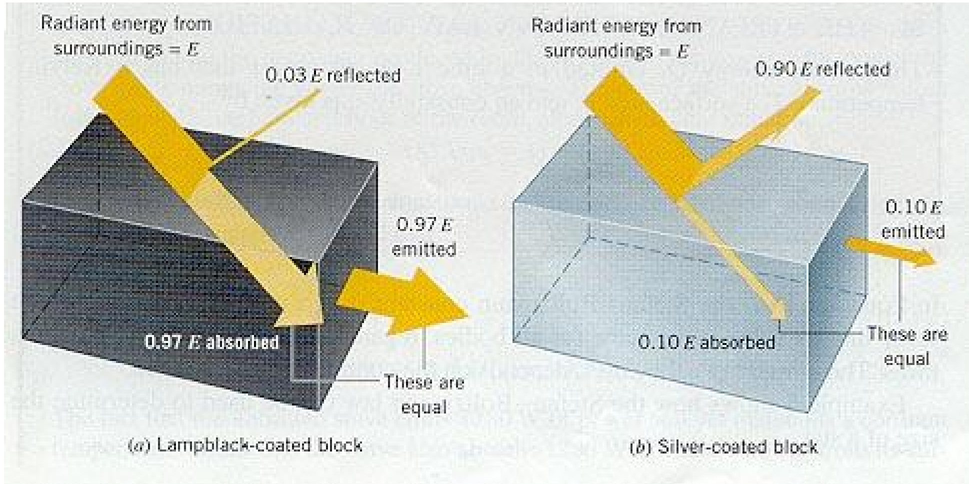
Convection:



Convection is heat transfer by the motion of fluid such as air or water when the heated fluid is caused to move away from the source of heat, carrying energy with it. Convection above a hot surface occurs because hot air expands, becomes less dense, and rises. Hot water is less dense than cold water and rises, causing convection currents which transfer energy.

Radiation:

Radiation is the heat transfer without the presence of any medium that is it can occur in vacuum. Radiation is the flow of heat from one place to another by means of electromagnetic waves.



Good and bad absorbers and emitters:

All bodies emit or absorb radiation mostly of infrared type. However

a) Dull black surfaces are better absorbers of radiation than white and shiny surfaces.
b) Dull black surfaces are better emitter of radiation than the shiny one.

CONDENSATION AND SOLIDIFICATION:

Condensation is the opposite of evaporation. It is the process of changing vapours into liquid by decreasing the temperature. For example the formation water droplets at the outer surface of colder water container or formation of clouds.

Freezing or solidification is the process in which liquid turns into a solid when temperature decreases enough. The freezing point is the temperature at which this happens. Melting, the process of turning solid into liquid is almost the exact opposite of freezing. All liquids undergo freezing when the temperature is lowered enough, with the sole exception of liquid helium, which remains liquid at absolute zero and can only be solidified under pressure. For most substances, the melting and freezing points are the same temperature.