CHAPTER ELEVEN

THERMAL PROPERTIES OF MATTER

The following points are to be discussed:

Temperature and heat

Measurement of temperature

Ideal-gas equation and absolute temperature

Thermal expansion

Specific heat capacity

Calorimetry

Change of state

Heat transfer

Newton’s law of cooling

Heat:

Heat is that form of energy that flows from one body to another body or it surrounding due to difference in temperature.

(Note only that energy which flows from one point to another due to difference in temperature is heat.)

Heat is measured in Joule/Calorie/kilocalorie.

Temperature:

Temperature is measure of degree of hotness or coldness of body.

(Note: Heat and temperature are related to each other as sugar and sweetness if you add sugar sweetness increases similarly when heat is given in any body temperature increases and when heat is removed temperature decreases.)

The S.I. Unit of Temperature is Kelvin (K) and some of the commonly used units are: Fahrenheit (°F) and Celsius (°C)

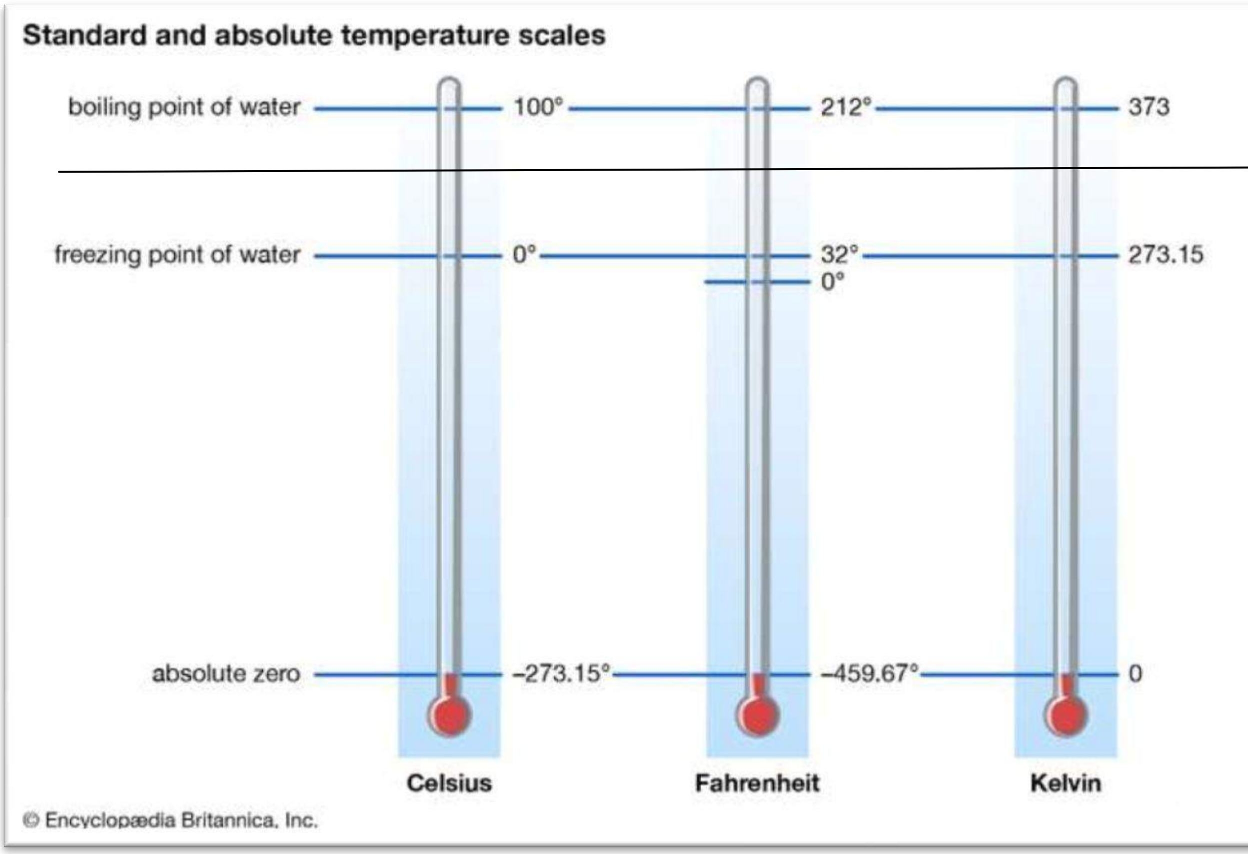
Measurement of temperature

To measure temperature the change that takes place due to temperature change is measured.

Any phenomenon in nature which takes place at a particular temperature is taken as reference.

For the definition of any standard scale, two fixed reference points are needed.

The ice point and the steam point of water are two convenient fixed points and are known as the freezing and boiling points. These two points are the temperatures at which pure water freezes and boils under standard pressure.



To find relation among different scales of temperature.

$$\frac{Upper\ fixed\ point - Lower\ Fixed\ point}{Total\ divisions\ between\ the\ two\ phenomena} = \textbf{Constant}$$

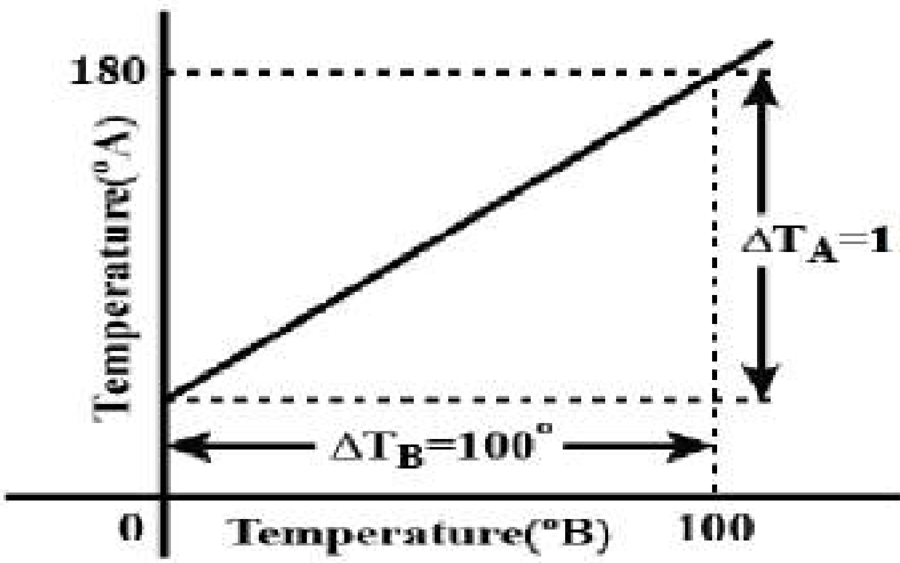
Natural phenomena in different Scale

Natural phenomena	Celsius	Fahrenheit	Kelvin
Boiling point of water	100^0 C	212^0C	373.15
Freezing point of water	0^0 C	32^0F	273.15
Number of divisions in the scale between boiling point and freezing point.	100	180	100
Any random phenomena temperature in different scale.	C	F	K

$$\frac{Reading\ in\ a\ particular\ scale - Lower\ Fixed\ point}{Total\ divisions\ between\ the\ two\ phenomena} = \text{Constant}$$

$$\frac{C-0}{100} = \frac{F-32}{180} = \frac{K-273.15}{100} = \text{constant}$$

This is because the slope of the graph is constant between two scales A and B.



Ideal-gas equation and absolute temperature

An equation which relates pressure P, temperature T and volume V of a gas is called gas equation.

Those gases which follow the gas equation are called ideal gas, but in actual practice the gases behavior varies such gases are called real gas.

The ideal gas equation is represented as-

$$PV=\mu RT$$

Where P= Pressure of the gas

V= Volume of the gas

μ = Number of moles of the gas

R = a constant called gas constant

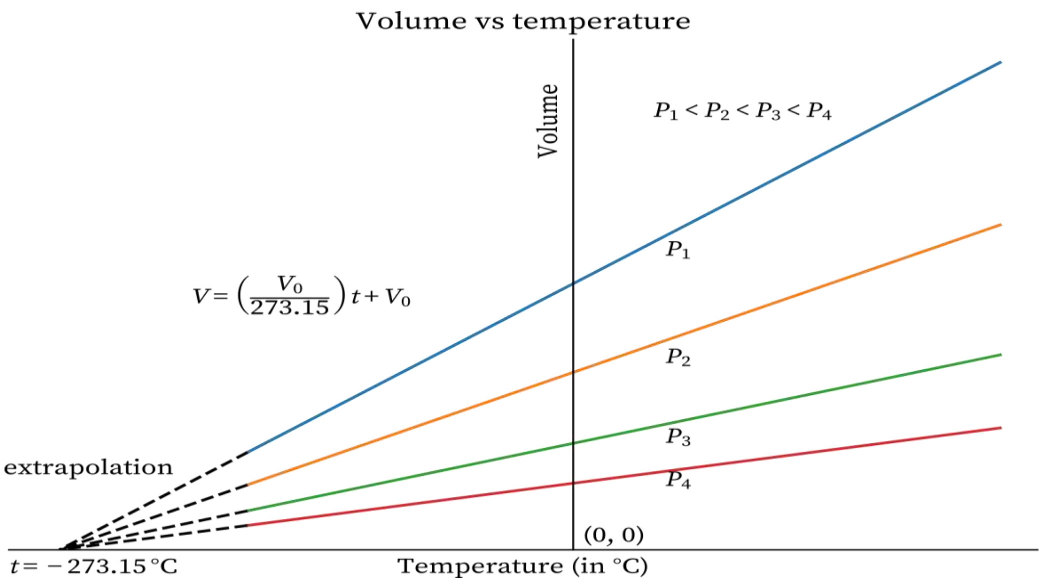
T = Temperature in Kelvin scale

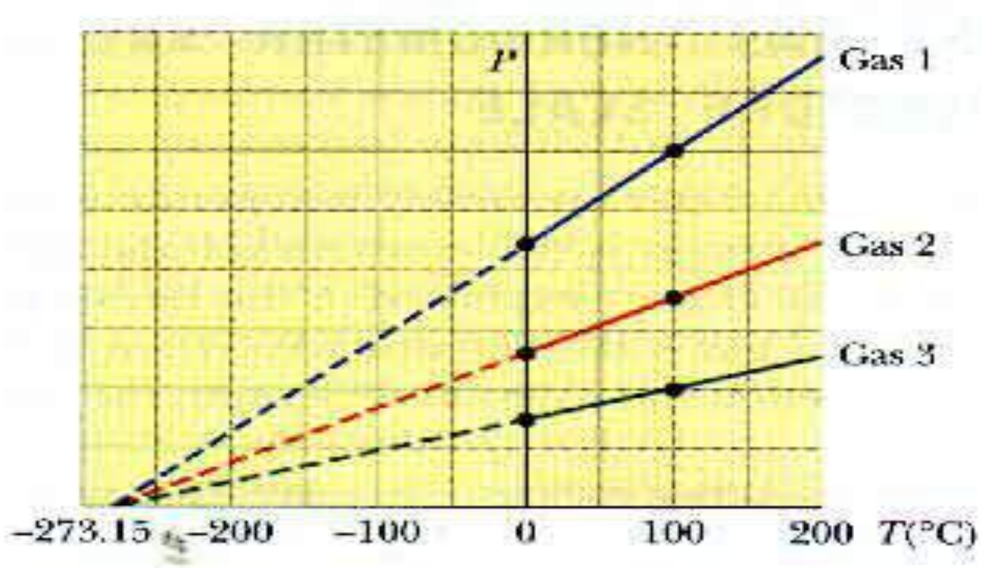
Here, $T = t+273.15$,t is temperature in Celsius scale.

When we put this in above equation-

$$PV=\mu R(t+273.15)$$

The graph between P &t and P & V is given –



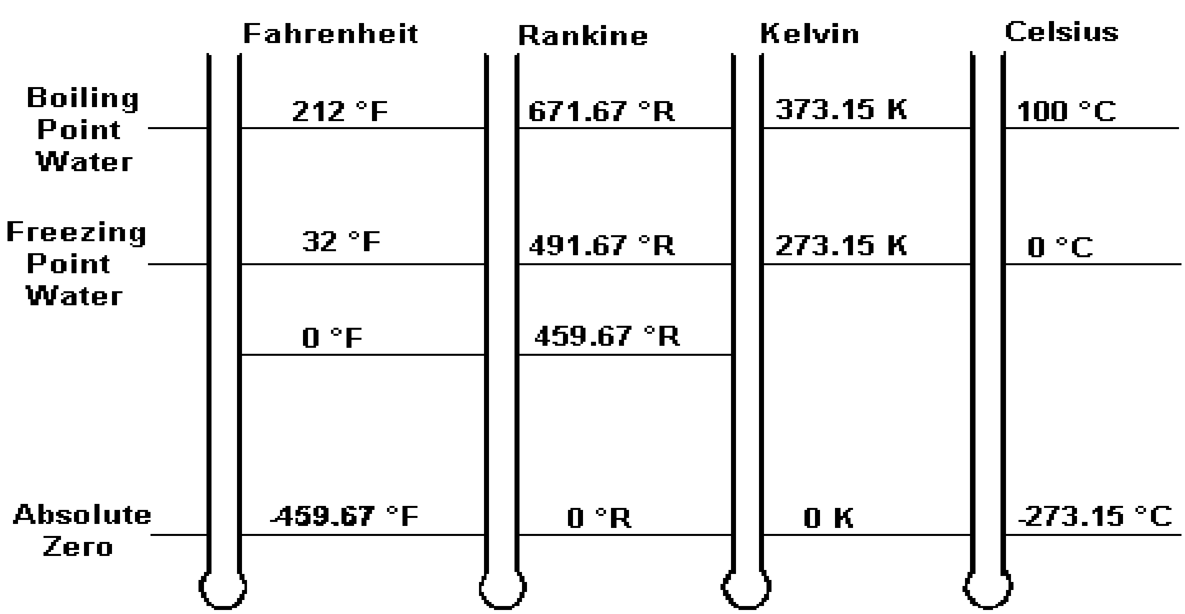


If V=0 or P=0

The t+ 273.15 = 0

Thus t = -273.15^0C .This temperature is called absolute zero temperature.

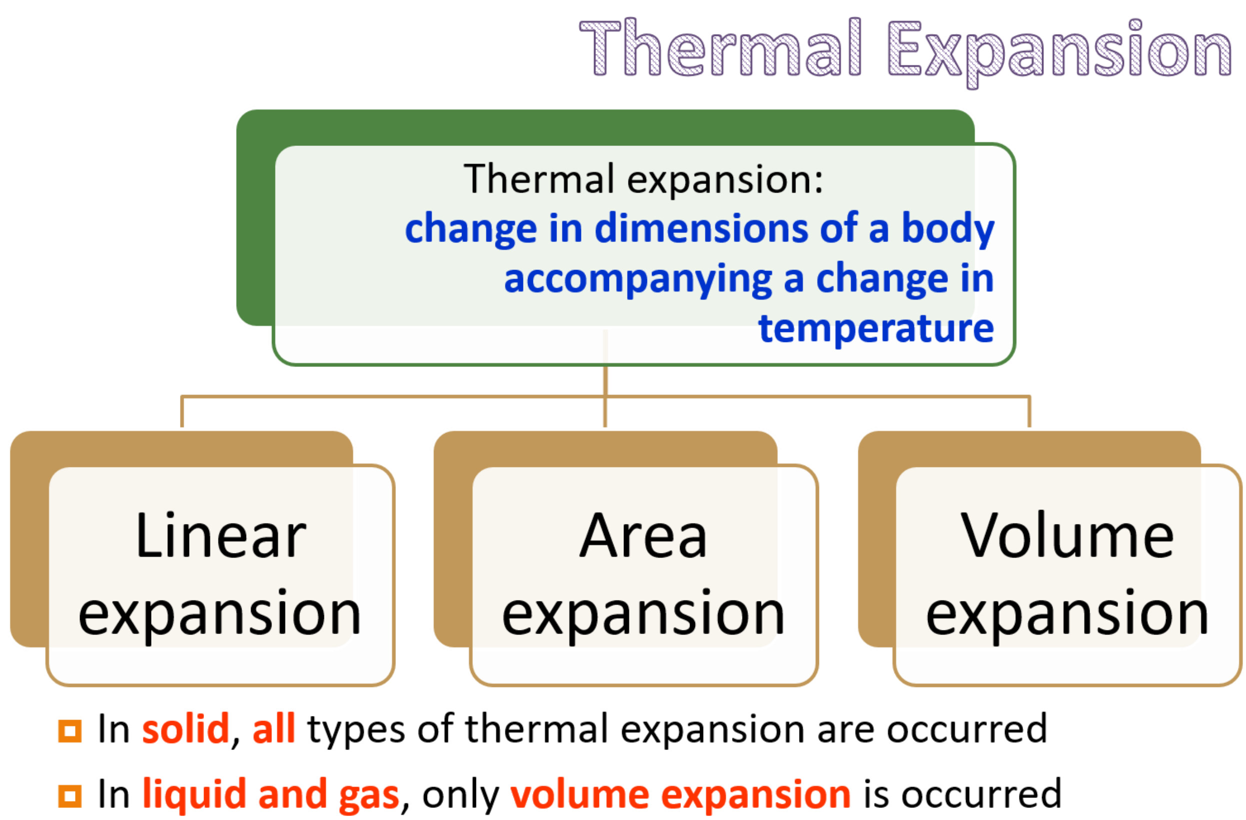
Thus the temperature at which pressure or volume of an ideal gas becomes is called absolute zero temperature. This is lower point of Kelvin scale. This temperature is 0K.(Which is equal to -273.15^0C)



Thermal expansion

The phenomenon of change in dimension (Length,Area or volume or all) due to heat of any material is called thermal expansion.

Thermal expansion may be classified as-



Linear expansion:- Change in length of a body due to change in temperature.

Area expansion:- Change in surface area of a body due to change in temperature.

Volume expansion:- Change in volume of a body due to change in temperature.

Coefficient of thermal expansion

Fractional change in dimension per unit change in temperature of a body is called coefficient of thermal expansion.

Fractional change is the change in dimension of a body with respect to original dimension.

Fractional change=$\frac{\boldsymbol{Change\ in\ dimension}}{\boldsymbol{Original\ dimension}}$

i.e., Fractional change in length =$\frac{\boldsymbol{Change\ in\ length}}{\boldsymbol{Original\ length}}$

It has been experimentally observed that the fractional change in dimension of body due to temperature is directly proportional to change in temperature.

Or the fractional change in the dimension of any object per unit temperature is constant.

Co-efficient of thermal expansions

Co-efficients ofthermal expansion:- The fractional change in length of a body is proportional to change in temperature.

Mathematically ,

$$\frac{\Delta l}{l} \propto \Delta T$$

$$\frac{\Delta l}{l} = \propto \Delta T$$

Where $\propto$ ***a constant is called co-efficient of liner expansion.***

Unit if $\propto$

$$\frac{\Delta l}{l \Delta T} = \propto$$

$\propto$***=*** $\frac{m}{mC}$***= per degree Celsius/Kelvin***

The co-efficient of linear expansion is fractional change is length of a body per unit change in temperature.

Similarly, co-efficient of area expansion (β***) and coefficient of coefficient of volume expansion (***γ***)may be defined.***

Relation between $\propto$ and β

Let us consider a body in the shape of square of surface area of the body is given as-

$$S = a^2$$

$$\text{Thus } \Delta S = 2a\Delta a$$

$$\text{Now , } \beta = \frac{\Delta S}{S\Delta T} = \frac{2a\Delta a}{S\nabla T} = \frac{2\Delta a}{a\nabla T} = 2 \propto \quad \left(\text{Since, } \propto = \frac{\Delta a}{a\nabla T}\right)$$

$$\text{Thus } \beta = 2 \propto$$

Relation between $\propto$ and γ

For a body in cubical shape

$$V = a^{3}, \qquad \text{Thus } \Delta V = 3a^2\Delta a$$

$\gamma = \frac{\Delta V}{V\nabla T}$ *on putting values of V and* ΔV

We get, $\gamma = 3 \propto$

HEAT CAPACITY

Heat capacity is the amount of heat required to Change the temperature of given mass of a substance per unit change in temperature.

$$S=\frac{\Delta Q}{\Delta T}$$

Where, S is heat capacity, ΔQ is heat absorbed or rejected and ΔT is change in temperature of body.

Specific heat capacity

Specific heat capacity is heat rejected or absorbed to raise the temperature per unit mass of a substance by unity.

Specific heat capacity is taken as per kilogram or per unit mole.

Specific heat capacity

$$S=\frac{Heat\ absorbed\ or\ rejected}{mass(in\ mole\ or\ kg)x change\ in\ temperature}$$

If heat capacity is taken in per mole of a substance it is called molar heat capacity.

In case of a gas there are two specific heat capacities

C_p and C_v, C_p is amount of heat absorbed or rejected per unit mole of a gas at constant pressure and C_v is heat absorbed of rejected per unit mole at constant volume.

$$C_p = \frac{\text{heat absorbed or rejectedat constant pressure}}{\text{number of moles x change in temperature}}$$

$$C_v = \frac{\text{heat absorbed or rejectedat constant volume}}{\text{number of moles x change in temperature}}$$

Unit of heat capacity is $Jmole^{-1}K^{-1}$ OR $Jkg^{-1}K^{-1}$.

CALORIMETRY

The study of measurement of heat is calorimetry.

A device in which heat measurement can be made is called a **calorimeter**

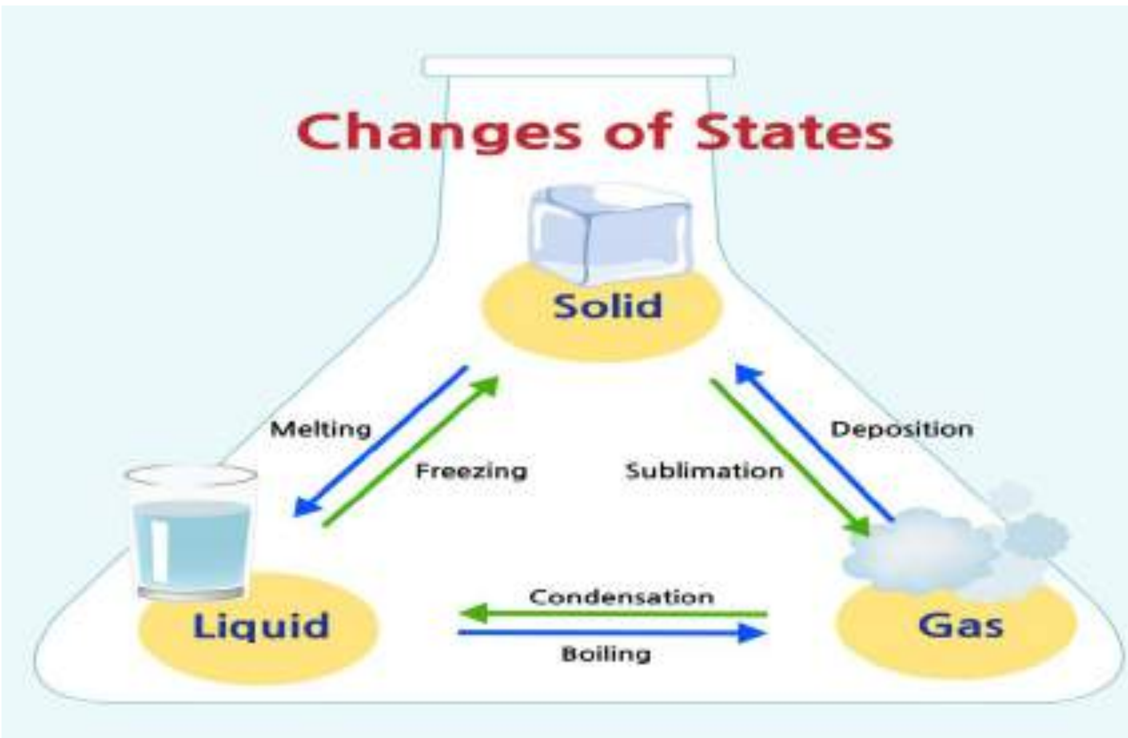
Principle of calorimetry

When two isolated bodies interact thermally the heat lost by one body is equal to heat gained by another body.

Heat Lost = Heat gained.

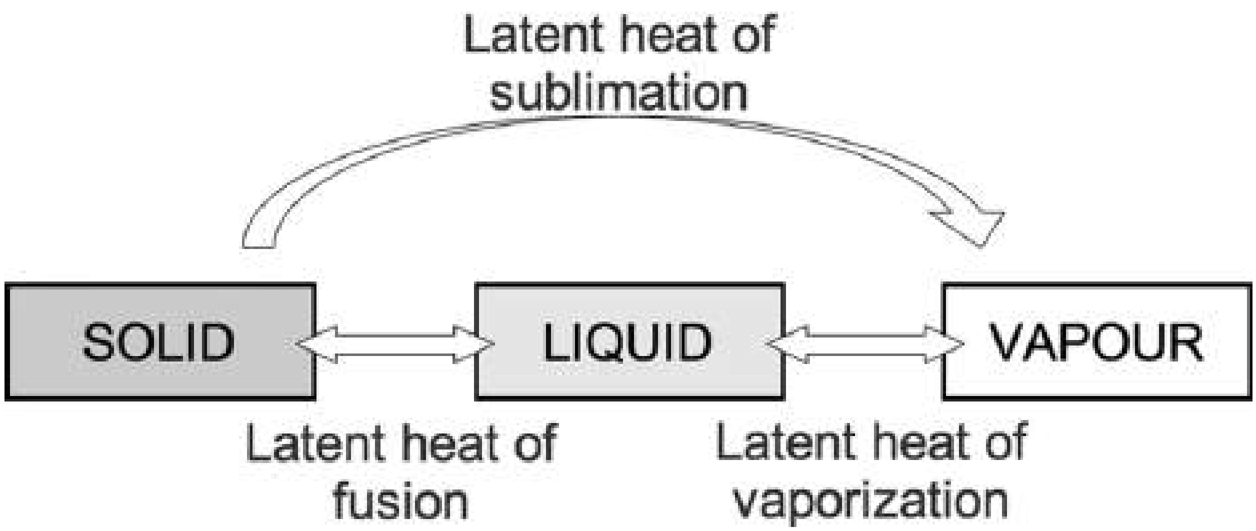
CHANGE OF STATE

Change in state is another effect of heat absorbed or heat rejected by a substance.



Whenever there is change in state of a body heat is absorbed or rejected by the body, this heat per unit mass is called latent heat.

It should be noted that change in state takes place at constant temperature and as the heat absorbed or rejected does not appear as rise or fall in temperature of the body this heat is called as latent heat.(The word latent means hidden)



Latent heat of fusion is heat absorbed when liquid is converted into solid, latent heat of vaporization when liquid is converted into vapor and vice versa.

Specific Latent Heat

- In Thermodynamics ! We saw that energy is needed to break inter-atomic attractions when a substance **melts** or **boils**.
- This energy is called **latent heat**.
- The temperature is constant during this change of state.
- The following equation is used to calculate energy needed for a change of state.

Heat transferred = mass x specific latent heat capacity

$$\Delta Q \text{ (J)} = m \text{ (kg)} \times L \text{ (J kg}^{-1}\text{)}$$

Specific latent heat, L is the energy needed to change the state of **1 kg** of the substance (without change in temperature).

Specific Latent Heat

Heat Energy

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

Mass

$$\mathbf{E} = \boldsymbol{m} \times \boldsymbol{L_v}$$

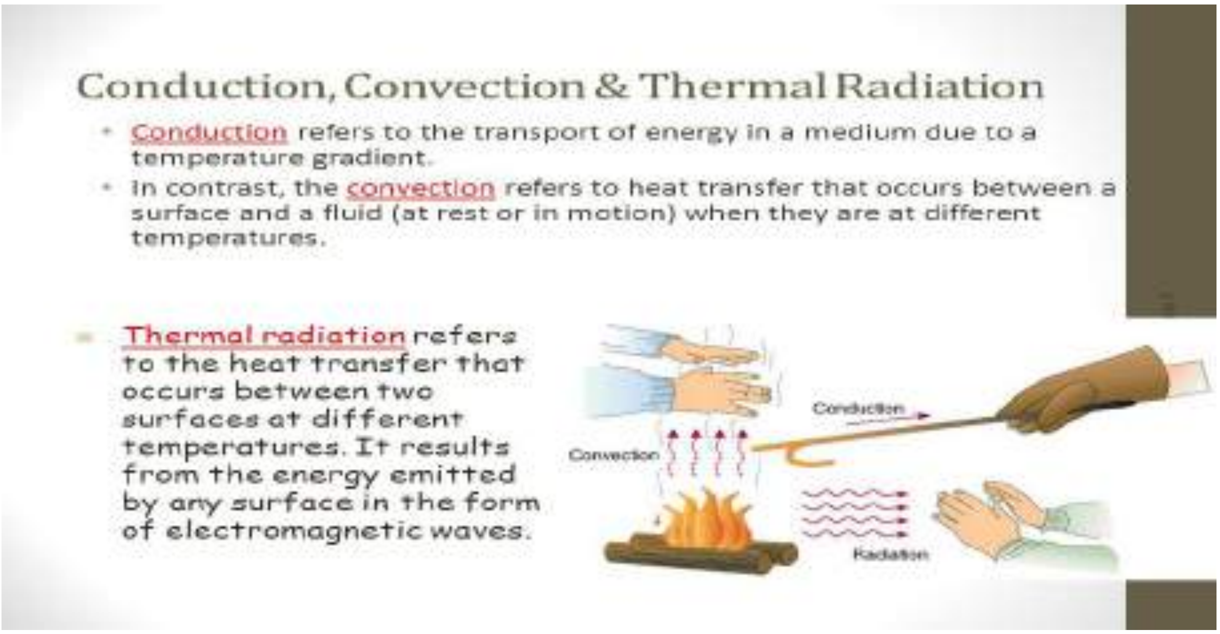
Where, m=mass of substance in kg
L_v= latent heat of vaporisation in J/kg
E= Energy in J

$$\mathbf{E} = \boldsymbol{m} \times \boldsymbol{L_f}$$

Where, m=mass of substance in kg
L_f= latent heat of fusion in J/kg
E= Energy in J

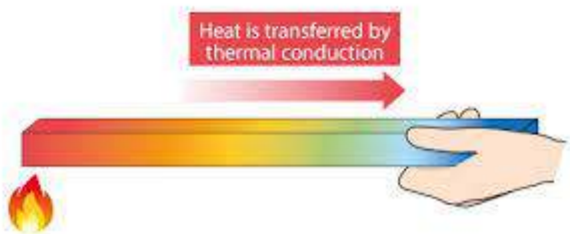
HEAT TRANSFER

The three modes of heat transfer are conduction, convection and radiation.

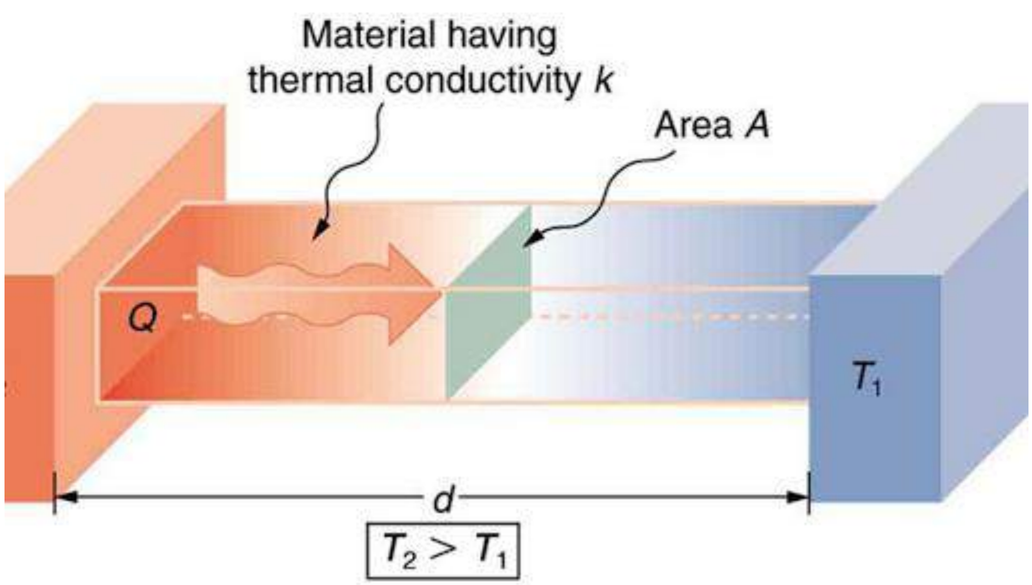


Conduction

Conduction is the mechanism of transfer of heat between two adjacent parts of a body because of their temperature difference.



Thermal conductivity



It has been observed that rate of heat flow during conduction is –

Directly proportional to the difference in temperature between two ends of the bodied.

Directly proportional to the cross-sectional area of the bodies.

Inversely proportional to the length of the body.

Rate of heat flow(Heat current)=KA$\frac{\Delta T}{d}$. Where ΔT=T_2-T_1.

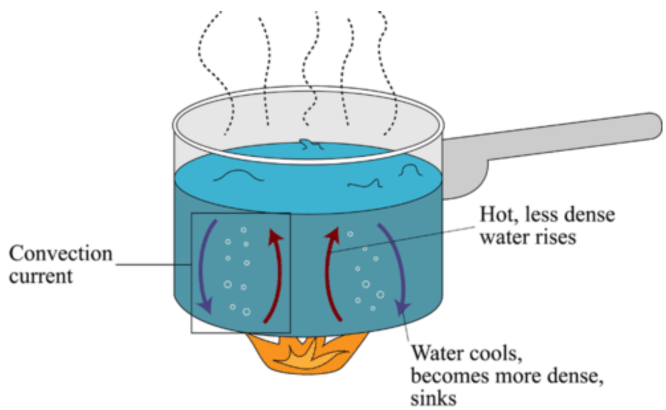
The SI unit of K is J S^{-1} m^{-1} K^{-1} or W m^{-1} K^{-1}.

Convection

Convection is a mode of heat transfer by actual motion of matter.

It is possible only in fluids.

Convection can be natural or forced.



Radiation

Radiation is that mode of transfer of energy in which no material medium is essential; in radiation the energy transfer takes place in the form of electromagnetic radiation.

Conduction	Convection	Radiation
In conduction, the heat transfer takes place between objects by direct contact.	In convection, the heat transfer takes within the fluid.	In radiation, the heat transfer occurs through electromagnetic waves without involving particles.
The heat transfer takes place due to the difference in temperature.	The heat transfer occurs due to the difference in density.	The heat transfer occurs in all object with temperature greater than 0 K.
The heat transfer in conduction is slow	The heat transfer in convection is faster.	The heat transfer in radiation is fastest.
The heat transfer occurs through a heated solid object.	The heat transfer occurs through intermediate objects. For example, heat transfer between air and water.	The heat transfer occurs through electromagnetic waves.
It does not follow the law of reflection and refraction.	It does not follow the law of reflection and refraction.	It follows the law of reflection and refraction.

NEWTON'S LAW OF COOLING

According to Newton's law of cooling "For small temperature difference rate of cooling of a body is directly proportional to difference in temperature of body and its surrounding.

If a hot body(at T) is kept in a surrounding (atT^0) and the body rejects dQ heat in time dt then rate of cooling is given as

R= $-\frac{dQ}{dt}$, the negative sign indicates that with time there is loss of heat.

Thus,

Rate of cooling $\propto$ difference in temperature between body and its surrounding.

$$-\frac{dQ}{dt}=k\Delta T=k(T-T^0)\text{.......................}(1)$$

If temperature falls by dT_2 in the same time dt. Then the heat lost is given as

$$dQ=ms\,dT$$

Rate of heat loss is $\frac{dQ}{dt}= msdT\frac{1}{dt}$

putting this value in (1)

$$msdT\frac{1}{dt}=k(T-T_0)$$

$$\frac{dT}{T-T^0}=\frac{k}{ms}dt= Kdt \qquad (\text{Where } K= \frac{k}{ms})$$

On integrating

$$\log_e(T-T^0) = Kt+ C$$

$$T-T^0 = e^{Kt+C}$$

$$T = T^0+ e^{Kt+C}$$

Experimental Verification of Newton’s law of cooling

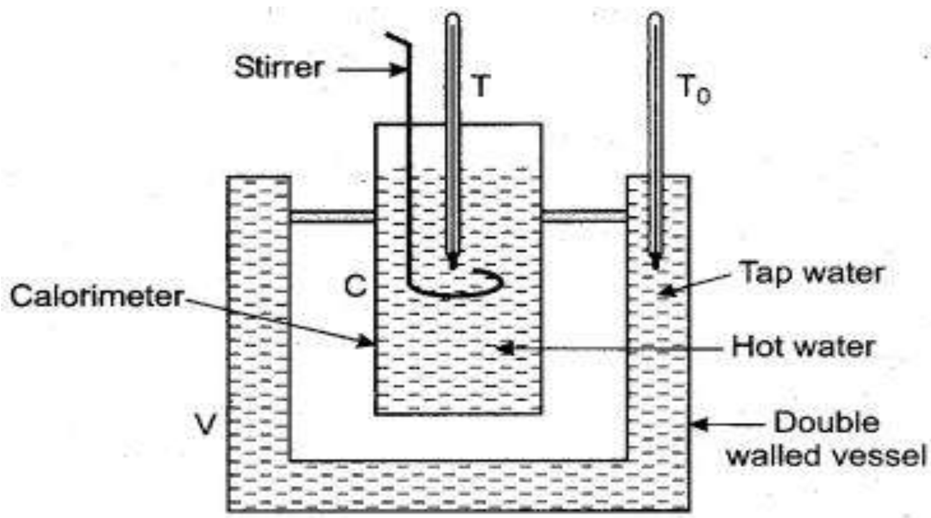
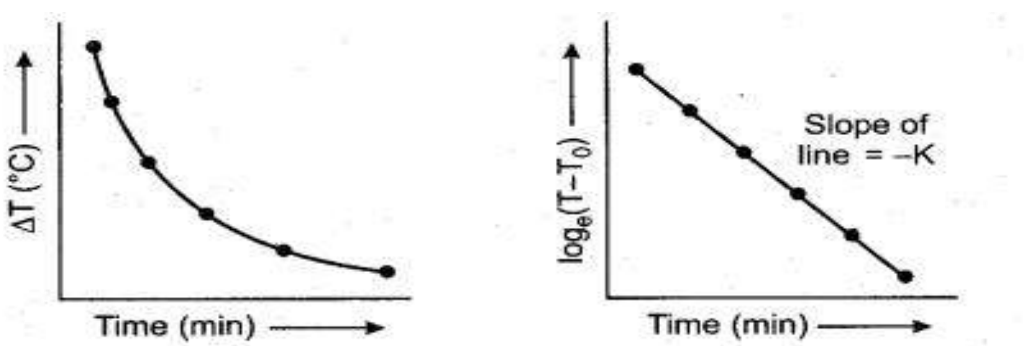


Fig. : Experimental set-up for verifying Newton’s law of cooling.

The experimental arrangement for the study of Newton’s law of cooking is shown in the figure, the values of T and T^0 is measured and recorded with time and a graph between $\log_e(T - T^0)$ with time is plotted the following graph is obtained…



(a) Curve showing cooling of hot water with time

(b) Straight line graph between $(T-T_0)$ and time t

[redacted]