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### **Introduction**

You might have noticed that you feel hotter on a sunny afternoon as compared to a windy night. This is because of the difference in temperatures. Temperature is very high in the afternoon as compared to night. This chapter basically gives us the

Examples: information about thermal properties of matter where we will study about the properties of different substances by virtue of heat / heat transfer.

In simple terms, we can say that when temperature is more heat is more and when temperature is less heat is less.

Hot Sunny day (Temperature is more) and ice cold water (Temperature is less).



### **Temperature and Heat**

Temperature is defined as the measure of degree of hotness or coldness of a body.

Example:-

- A cup of hot soup or a scoop of Ice-cream.



Heat is the form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference.

For e.g.:- a cup of hot coffee can be considered as object or system and anything apart from hot coffee is surroundings. Then the heat will flow from one object to another as there is difference in temperature.



After some time we will see this hot cup of coffee will become cold as there will be transfer of heat.

The S.I Unit of Heat is joule (J) and some of the commonly used units are: calorie and kilocalorie

### Relation between Joule and Calorie

1calorie=4.18 Joules

1kilocalorie = 1000 calories

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**

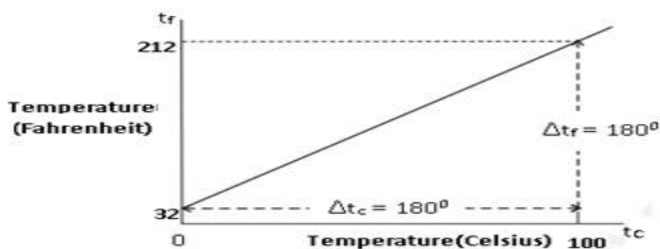
Temperature is measured with the help of thermometer. Mercury and Alcohol are commonly used liquids in the liquid-in-glass thermometers.

- To construct a thermometer two fixed points are to be chosen as a reference points. These fixed points are known as freezing(ice point) and boiling point(steam point). The water freezes and boils at these two points under standard pressure.
- The ice and steam point in Fahrenheit Temperature scale are 32°F and 212 °F resp.It has 180 equal intervals between two reference points.
- On Celsius Scale values are 0°C and 100°C for ice and steam point resp. It has 100 equal intervals between two reference points.



### Mercury-in-Thermometer

Graphically the relation between the temperature in Celsius and in Fahrenheit is given by the following graph:-



And whose equation is:

$$(t_f - 32)/180 = t_c/100$$

Where  $t_f$  = Fahrenheit temperature

$t_c$  = Celsius temperature

## Ideal-gas Equation and Absolute Temperature

A thermometer that uses any gas, however, gives the same readings regardless of which gas is used because all gases have same expansion at low temperature.

Variables that describe the behaviour of gas are:-

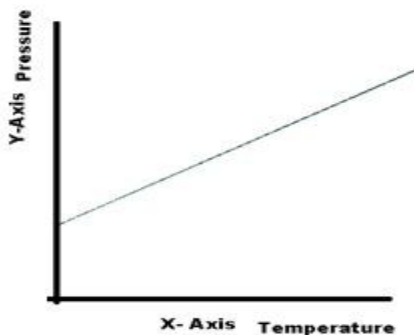
- Quantity(mass)
- Pressure
- Volume
- Temperature i.e. (P,V,T) where  $(T = t + 273.15; t$  is the temperature in  $^{\circ}\text{C}$ )

Gases which have low density obey certain laws: -

1. **Boyle's Law**–  $PV = \text{constant}$ (when temperature T is constant)

2. **Charles' Law**-  $V/T = \text{constant}$  (when pressure P is constant)

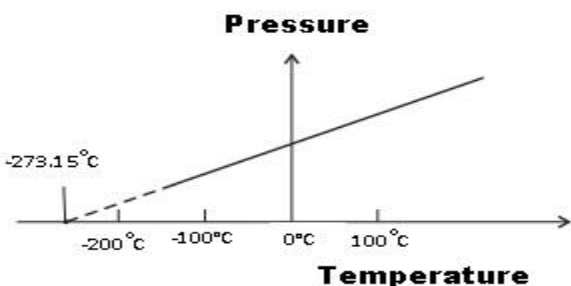
- If combine both the above laws the equation becomes  $PV = RT$  where R is called **universal gas constant** and its value =  $8.31 \text{ J mol}^{-1} \text{ K}^{-1}$ .
- $PV = RT$  is the ideal gas equation which is applicable only at low temperature.
- For any quantity of dilute gas,  
 $PV = \mu RT$  where  $\mu$ , is the number of moles in the sample of gas.
- In a constant volume gas thermometer temperature varies with respect to pressure. Temperature changes linearly with increase in pressure.



### Absolute Zero

Absolute Zero is defined as minimum absolute temperature of an ideal gas.

- If we plot pressure versus temperature we get a straight line and if we extend the line backwards to the x-axis as shown in the graph below. The minimum temperature is found to be  $273.15^{\circ}\text{C}$  (experimentally) and this value is known as absolute zero.
- The relation between the temperature in kelvin and in Celsius scale is given by  
 $T = t_{\text{C}} + 273.15$



**Problem:** The triple points of neon and carbon dioxide are 24.57 K and 216.55 K respectively. Express these temperatures on the Celsius and Fahrenheit scales?

**Solution:** Celsius and Fahrenheit scales are related as

$$T_F = (9/5)T_C + 32 \quad \dots \text{(ii)}$$

For neon:

$$= 24.57 \text{ K}$$

$$= 24.57 - 273.15 = -248.58^\circ\text{C}$$

$$T_F = (9/5) T_C + 32$$

$$= 9/5(-248.58) + 32$$

$$= 415.44^\circ\text{F}$$

For carbon dioxide:

$$= 216.55 \text{ K}$$

$$= 216.55 - 273.15 = -56.60^\circ\text{C}$$

$$T_F = (9/5)T_C + 32$$

$$= 9/5(-56.60) + 32$$

$$= -69.88^\circ\text{C}$$

**Problem:** Two absolute scales A and B have triple points of water defined to be 200 A and 350 B. What is the relation between  $T_A$  and  $T_B$ ?

**Solution:**

Triple point of water on absolute scale A,  $T_1 = 200 \text{ A}$

Triple point of water on absolute scale B,  $T_2 = 350 \text{ B}$

Triple point of water on Kelvin scale,  $T_k = 273.15 \text{ K}$

The temperature 273.15 K on Kelvin scale is equivalent to 200 A on absolute scale A.

$$T_1 = T_k$$

$$200 \text{ A} = 273.15 \text{ K}$$

Therefore,

$$A = 273.15/200$$

The temperature 273.15 K on Kelvin scale is equivalent to 350 B on absolute scale B.

$$T_2 = T_k$$

$$350 \text{ B} = 273.15$$

$$B = 273.15/350$$

$T_A$  is triple point of water on scale A.  $T_B$  is triple point of water on scale B

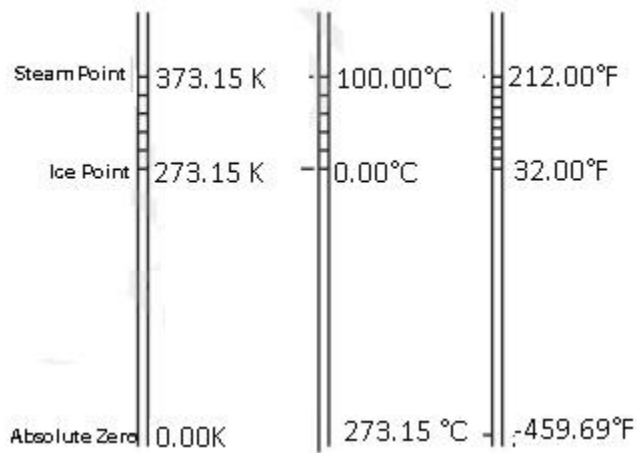
Therefore,

$$\frac{273.15}{200} \times T_A = \frac{273.15}{350} \times T_B$$

$$T_A = \frac{200}{350} T_B$$

Therefore, the ratio  $T_A : T_B$  is given as 4: 7.

## Comparison of Kelvin, Celsius and Fahrenheit temperature Scales



### **Thermal Expansion**

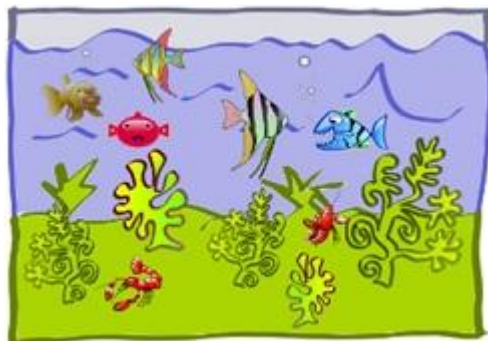
- Thermal expansion is the phenomenon of increase in dimensions of a body due to increase in its temperature.

### **Examples of Thermal Expansion**

- The water is cold at the top of the lake because it expands and becomes less dense. So when this water freezes it insulates the water below it from the outside which means cold air is like a blanket. It is because of this property many fish can survive in the winter.



(1)



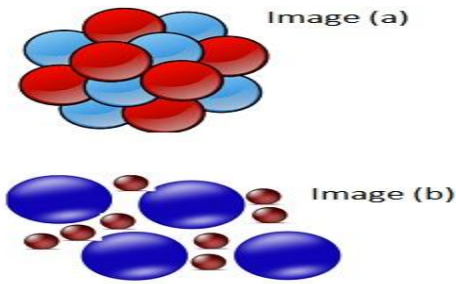
Even though the top layer of water is frozen as we can see in the image (1), the plant and animal life is not getting affected as shown in the image (2).

- As soon as we turn on a hot water tap, the water comes very fast as water is still cold. But as soon as hot water starts coming, the flow of water becomes less and in some cases it stops. This is because the hot water heats the metal valve inside the tap which expands to block off any more flow of water.



Reason why Thermal Expansion happens is:-

- When any object is heated particles start moving in random motion and thus average distance between the molecules increases and as a result the object appears to be expanded when heated. As we can see the picture below atoms are tightly packed but when we apply heat they will start moving in random motion.



As we can see in the Image (a) molecules are very tightly packed but when heated the molecules start moving apart in random motion, which can be seen in Image (b).

- When an object is cooled it contracts which is referred to as negative thermal expansion.

### Types of Thermal Expansion

1. Linear Expansion :- The expansion in length
2. Area Expansion :- The expansion in area
3. Volume Expansion :- The expansion in volume

#### Linear Expansion

Linear Expansion means expansion in length due to increase in temperature. Linear expansion means fractional change in length i.e. how the length is changing with respect to original length.



As we can see from above images the length has been increased from  $l$  to  $l + \Delta l$ .

Coefficient of Linear Expansion is a parameter which tells us how the size of the object changes with change in temperature. It is defined as degree of linear expansion divided by the change in temperature.

- If the solid is in the form of a long rod, then for a small change in temperature,  $\Delta T$ , the fractional change in length,  $\Delta l/l$ , is directly proportional to  $\Delta T$ . Mathematically it can be written as:-

$$\frac{\Delta l}{l} = \alpha_1 \Delta T$$

Where  $\alpha_1$  = the coefficient of linear expansion

It is denoted by  $\alpha_1$

- It is characteristic of the material of the rod. It varies for different substances.

### Example

- Automatic hot water kettle switches off on its own when the water boils.
- Metals expand more and have higher value of coefficient of linear expansion.

### Area Expansion



Area Expansion can be defined as expansion in area due to increase in temperature. In case of area expansion there is increase in both length wise and breadth wise.

As we can see from above images the area of the cube has been increased from  $A$  to  $A + \Delta A$ .

Mathematically can be written as:-

$$\frac{\Delta A}{A} = \alpha_a \Delta T$$

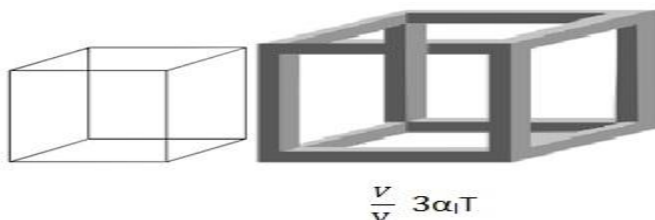
Where  $\alpha_a$  = coefficient of area expansion.

Coefficient of Area Expansion is defined as degree of area expansion divided by the change in temperature. This means there is increase in area of an object with the change in temperature.

- It is denoted by  $\alpha_a$
- It is characteristic of the substance and it varies with temperature.

### Volume Expansion

It can be defined as expansion in volume due to increase in temperature. This means there is increase in length, breadth and height of a substance.



- As we can see from above images the volume of the cube has been increased from  $V$  to  $V + \Delta V$  there is increase in length, width and height.
- The expansion in volume due to increase in temperature. Mathematically can be written as:-

$$\frac{\Delta V}{V} = \alpha_v \Delta T$$

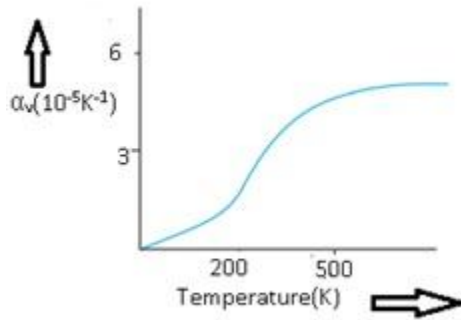
Where  $\alpha_v$  = coefficient of volume.

Coefficient of Volume can be defined as degree of volume expansion divided by change in temperature.

- It is denoted by  $\alpha_v$ .
- It is characteristic of the substance
- It varies with temperature.

If graph is plotted between  $\alpha_v$  and temperature, then initially  $\alpha_v$  is changing linearly then it varies non-linearly and at higher temperatures and then it becomes constant.

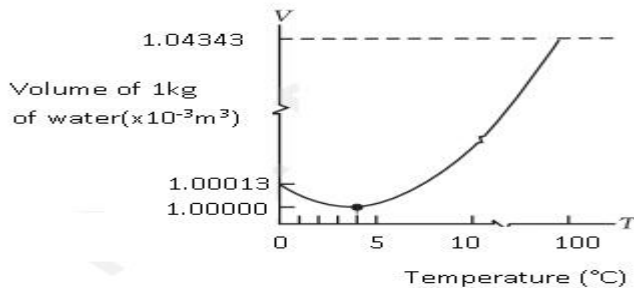
## Coefficient of volume expansion of copper as a function of temperature-



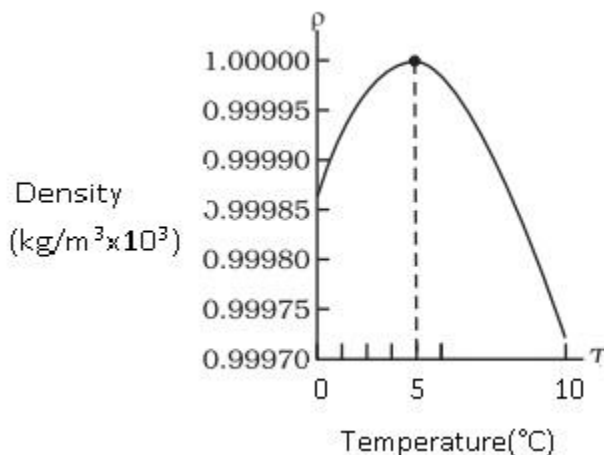
**Thermal expansion of solids and liquids are small.**

### Anomalous Behaviour of Water

- Water shows some exceptional behaviour that is when it is heated at  $0^\circ\text{C}$ , it contracts instead of expanding and it happens till it reaches  $4^\circ\text{C}$ . The volume of a given amount of water is minimum at  $4^\circ\text{C}$  therefore its density is maximum (Refer the Fig). After  $4^\circ\text{C}$  water starts expanding. Below  $4^\circ\text{C}$ , the volume increases, and therefore the density decreases. This means water has maximum density at  $4^\circ\text{C}$ .
- Advantages of Anomalous behaviour of Water
- Because of this property of water in lakes and ponds freeze only at the top layer and at the bottom it does not, but if the water freezes at the bottom also then animal and plant life would not be possible.



If we plot temperature on X-axis and Density on Y-Axis we will obtain the graph as given below:-

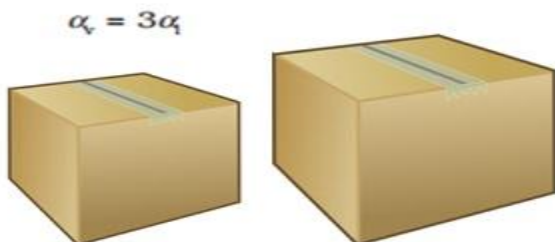


The information we get from the above graph means that the density increases as its temperature rises from  $0^\circ\text{C}$  to  $4^\circ\text{C}$  and density decreases after  $4^\circ\text{C}$ .



## Relation between $\alpha_v$ and $\alpha_l$

- Relation between coefficient of linear expansion and coefficient of volume expansion =



To derive the above relation consider a block of cube initially its length is  $l$ , suppose temperature is increased  $T + \Delta T$  as a result length will also increase from  $(l + \Delta l)$

Then  $\alpha_l = (\Delta l / l) / \Delta T$

Therefore,  $\alpha_l l \Delta T = \Delta l$

Also as the temperature increases by  $\Delta T$  the volume also increases  $V + \Delta V$

Where  $\Delta V =$  change in volume which we can write as

$$\Delta V = (l + \Delta l)^3 - l^3$$

By solving we get  $\Delta V = 3l^2 \Delta l$  (we are neglecting  $(\Delta l)^2$  and  $(\Delta l)^3$  as they are very small as compared to  $l$ ).

$$\begin{aligned} \text{Therefore, } \Delta V &= (3V \Delta l) / l \\ &= 3V \alpha_l \Delta T \end{aligned}$$

Which gives  $\alpha_v = 3\alpha_l$  the relation between coefficient of volume expansion and coefficient of linear expansion.

## Thermal stress:

- Mechanical stress induced by a body when some or all of its parts are not free to expand or contract in response to change in temperature.
- When an object is heated or cooled either it expands or it contracts but if for some reason if the object is not allowed to expand to contract under that case mechanical stress is induced in the body which is known as Thermal Stress.
- Example :-

While designing structures like concrete highways gaps are left which are filled by some flexible material so that concrete is allowed to expand or contract.



## Heat Capacity

The change in temperature of a substance, when a given quantity of heat is absorbed or rejected by substance is characterised by a quantity called the heat capacity of that substance.

- It is denoted by  $S$ .
- It is given as  $S = \Delta Q / \Delta T$

Where  $\Delta Q =$  amount of heat supplied to the substance and  $T$  to  $T + \Delta T$  change in its temperature.

### Specific heat capacity:

- Every substance has a unique value for the amount of heat absorbed or rejected to change the temperature of unit mass of it by one unit. This quantity is referred to as the specific heat capacity of the substance.

Mathematically can be written as:-

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

Where  $\Delta Q$  = amount of heat absorbed or rejected by a substance

$\Delta T$  = temperature change

### **Specific Heat Capacity**

- Specific heat is defined as the amount of heat per unit mass absorbed or rejected by the substance to change its temperature by one.

Mathematically can be written as:-

$$s = \frac{S}{m} = \frac{1}{m} \frac{\Delta Q}{\Delta T}$$

Where

- $\Delta Q$  = amount of heat absorbed or rejected by a substance
- $m$  = mass
- $\Delta T$  = temperature change
- It depends on the nature of the substance and its temperature.
- The SI unit of specific heat capacity is  $\text{J kg}^{-1} \text{K}^{-1}$ .

### **Molar specific heat capacity: -**

- Heat capacity per mole of the substance is defined as the amount of heat (in moles) absorbed or rejected (instead of mass  $m$  in kg) by the substance to change its temperature by one unit.

Mathematically can be written as:-

$$C = S / \mu = \Delta Q / \mu \Delta T$$

Where

- $\mu$  = amount of substance in moles
- $C$  = molar specific heat capacity of the substance.
- $\Delta Q$  = amount of heat absorbed or rejected by a substance.
- $\Delta T$  = temperature change

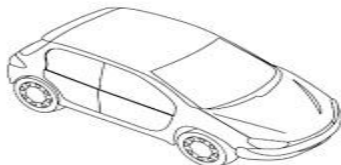
It depends on the nature of the substance and its temperature. The SI unit of molar specific heat capacity is  $\text{J mol}^{-1} \text{K}^{-1}$

### **Molar specific heat capacity ( $C_p$ ):-**

- If the gas is held under constant pressure during the heat transfer, then the corresponding molar specific heat capacity is called molar specific heat capacity at constant pressure ( $C_p$ ).

### Molar specific heat capacity ( $C_v$ ):-

- If the volume of the gas is maintained during the heat transfer, then the corresponding molar specific heat capacity is called molar specific heat capacity at constant volume ( $C_v$ ).
- Water has highest specific heat of capacity because of which it is used as a coolant in automobile radiators and in hot water bags.



**Problem:-** In an experiment on the specific heat of a metal, a 0.20 kg block of the metal at 150 °C is dropped in a copper calorimeter (of water equivalent 0.025 kg) containing 150 cm<sup>3</sup> of water at 27 °C. The final temperature is 40 °C. Compute the specific heat of the metal. If heat losses to the surroundings are not negligible, is your Solution greater or smaller than the actual value for specific heat of the metal?

**Solution:-** Mass of the metal,  $m = 0.20 \text{ kg} = 200 \text{ g}$

Initial temperature of the metal,  $T_1 = 150^\circ\text{C}$

Final temperature of the metal,  $T_2 = 40^\circ\text{C}$

Calorimeter has water equivalent of mass,  $m' = 0.025 \text{ kg} = 25 \text{ g}$

Volume of water,  $V = 150 \text{ cm}^3$

Mass (M) of water at temperature  $T = 27^\circ\text{C}$ :  $150 \times 1 = 150 \text{ g}$

Fall in the temperature of the metal:

$$\Delta T = T_1 - T_2 = 150 - 40 = 110^\circ\text{C}$$

Specific heat of water,  $C_w = 4.186 \text{ J/g}^\circ\text{K}$

Specific heat of the metal =  $C$

Heat lost by the metal,  $\theta = mC\Delta T \dots (i)$

Rise in the temperature of the water and calorimeter system:

$$\Delta T = 40 - 27 = 13^\circ\text{C}$$

Heat gained by the water and calorimeter system:

$$\Delta\theta' = m' C_w \Delta T'$$

$$= (M + m') C_w \Delta T' \dots (ii)$$

Heat lost by the metal = Heat gained by the water and calorimeter system

$$mC\Delta T = (M + m') C_w \Delta T'$$

$$200 \times C \times 110 = (150 + 25) \times 4.186 \times 13$$

$$\frac{175 \times 4.186 \times 13}{110 \times 200} = 0.43 \text{ Jg}^{-1} \text{ K}^{-1}$$

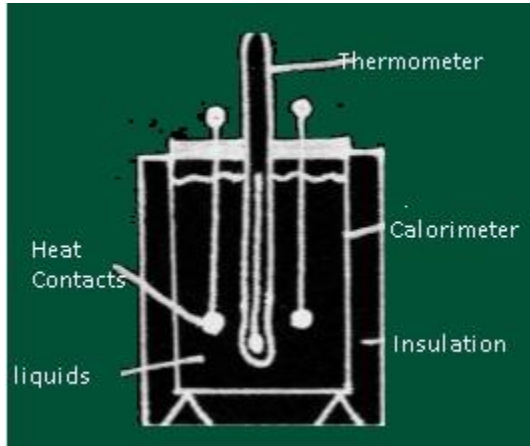
If some heat is lost to the surroundings, then the value of  $C$  will be smaller than the actual value.

### Calorimetry

Calorimetry is made up of 2 words:-

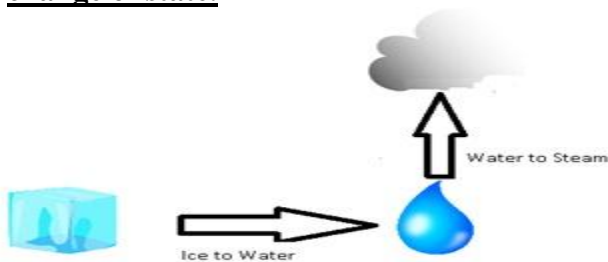
- Calorie which means heat and metry means measurement. Therefore Calorimetry means measurement of heat.
- Calorimetry is defined as heat transfers from a body at a higher temperature to a body at a lower temperature provided there is no loss of heat to the atmosphere.

- Principle of Calorimetry is heat lost by one body is equal to the heat gained by another body.
- The Device which measures Calorimetry is known as **Calorimeter**.
- Description of Calorimeter
- A calorimeter consists of metallic vessel and a stirrer both are made of same material (copper or aluminium) and the vessel is kept in a wooden jacket so that there is no heat loss .A mercury thermometer can be inserted through a small opening in the outer jacket.



### Change of State

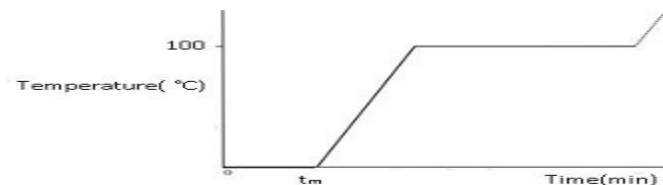
The transition from either solid to liquid or gas and gas to either liquid or solid is termed as **change of state**.



We can from the above image solid (ice) changes to liquid (water) and liquid changes to vapour(gas).

Change from solid (ice) to liquid (water) is known as **Melting**.

Change from liquid (water) to solid (ice) is known as **Fusion**.



**Thermal Equilibrium**: - At this state there is no loss or gain of heat takes place.

The temperature at which the solid and the liquid states of the substance are in thermal equilibrium with each other is called its **melting point**.



It depends on the

- substance
- Pressure.

The melting point of a substance at standard atmospheric pressure is called its **normal melting point**.

**Regelation:-**

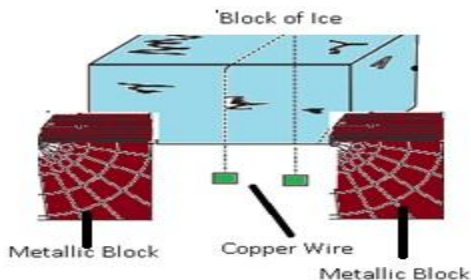
- Regelation can be defined as phenomenon in which the freezing point of water is lowered by the application of pressure.

Example:-



Cause of regelation:-

- If we have a block of ice and a copper wire pulled by two masses if we will observe that copper wire can pass through ice block this is because copper is good conductor of heat so as it passes through the ice it gets refreeze as the copper will generate heat and this heat will pass quickly to the ice below and it starts melting because there is increase in pressure which lowers temperature as a result the wire will move through the ice. This happens because of regelation.



The image above explains how a copper wire can pass through the block of ice.

**Vaporisation:** - Transition from liquid to vapour.

- The change of state from liquid to vapour (or gas) is called vaporisation.



- The temperature at which the liquid and the vapour states of the substance coexist is called its boiling point.
- Boiling point at standard atmospheric pressure is known as normal boiling point.
- It depends on nature of substance & pressure
- It increases with increase in pressure and vice versa.

**Example:** As altitude increases, the density of the air becomes thinner, and thus exerts less pressure. At high altitudes, external pressure on water is therefore decreased and will hence take less energy to break the water. If less energy is required it means less heat and less temperature which means that water will boil at a lower temperature.

**Sublimation: - Transition from Solid to Vapour.**

During the sublimation (solid changes to vapour without going through liquid state) process both the solid and vapour states of a substance coexist in thermal equilibrium.

Example:-

- Dry ice (solid CO<sub>2</sub>) sublimates iodine.
- Naphthalene balls sublimates to gaseous state.



Thank You

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