CHAPTER ELEVEN

THERMAL PROPERTIES OF MATTER

(***Prepared By Ayyappan C, HSST Physics, GHSS Udma, Kasaragod, Mob: 9961985448***)

HEAT AND TEMPERATURE

- ***Heat*** is a form of energy transferred between two (or more) systems or a system and its surroundings by virtue of temperature difference.
- ***Temperature*** is a measure of hotness of a body.
- The SI unit of heat energy transferred is expressed in ***joule (J).***
- SI unit of temperature is kelvin (K), and °C is a commonly used unit of temperature.
- Conventionally, the heat energy Q supplied to a body is taken to be positive (+Q) and the heat energy given out of a body is taken to be negative (-Q).

MEASUREMENT OF TEMPERATURE

- A measure of temperature is obtained using a ***thermometer.***
- The commonly used property is variation of the volume of a liquid with temperature.
- Commonly used thermometer scales are:

(i) Celsius scale (^{0}C)
(ii) Kelvin scale (K)
(iii) Fahrenheit scale (^{0}F)

Relation between different temperature scales.

At standard pressure

- Freezing point of water: 0^{0}C 32 ^{0}F 273.15 K - Lower fixed point
- Boiling point of water : 100 ^{0}C 212 ^{0}F 373.15 K. - Upper fixed point.
- In Celsius scale and Kelvin scale, the temperature difference between freezing point and boiling point of water are the same.
- These are related by

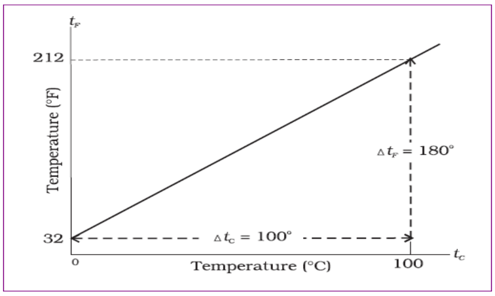
$$\boxed{T = t_C + 273.15}$$

- 0K is called ***absolute zero***, because below this value we cannot find any temperature in the universe.

Conversion of temperature from one scale to another.

$$\frac{\text{temp on one scale} - \text{lower fixed point}}{\text{upper fixed point} - \text{lower fixed point}} = \frac{\text{temp on another scale} - \text{lower fixed point}}{\text{upper fixed point} - \text{lower fixed point}}$$

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



Boyle's law

- When temperature is held constant, the pressure and volume of a quantity of gas are related as *PV = constant.*

Charles' law

- When the pressure is held constant, the volume of a quantity of the gas is related to the temperature as *V/T = constant*

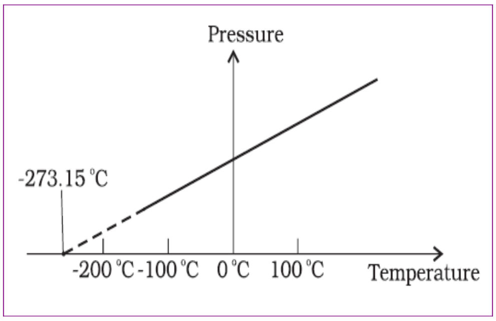
Ideal-gas equation

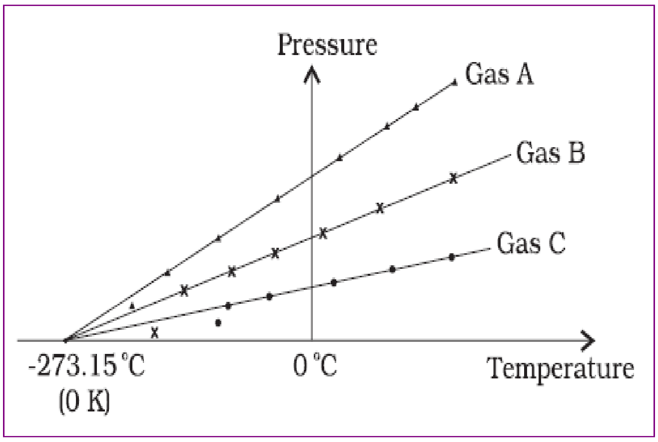
$$\frac{PV}{T} = \mu R$$
$$\text{or } PV = \mu RT$$

$$\boxed{R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}}$$

- where, μ is the number of moles in the sample of gas and *R is called* ***universal gas constant.***

Pressure versus temperature of a low density gas kept at constant volume.





- With a constant-volume gas thermometer, temperature is read in terms of pressure.
- The absolute minimum temperature for an ideal gas is – 273.15 °C and is designated as **absolute zero.**
- Absolute zero is the foundation of the Kelvin temperature scale or absolute scale temperature

THERMAL EXPANSION

- The increase in the dimensions of a body due to the increase in its temperature is called thermal expansion.
- The expansion in length is called **linear expansion.**
- **The expansion in area is called area expansion.**
- **The expansion in volume is called volume expansion.**
- ***The fractional change in dimension [ratio of change in dimension to original dimension] is proportional to change in temperature***.
- The corresponding proportionally constant is called **co-efficient of thermal expansion or thermal expansivity.**

Type of thermal expansion	Linear expansion	Area expansion	Volume expansion
The dimension that changes	length	Area	Volume
Coefficient of	$\alpha_\ell = \frac{\Delta\ell}{\ell\Delta T}$	$\alpha_a = \frac{\Delta A}{A\Delta T}$	$\alpha_v = \frac{\Delta V}{V\Delta T}$
thermal expansion (α)	linear expansivity or co-efficient of linear expansion	Area expansivity or co-efficient of area expansion	Volume expansivity or coefficient of volume expansion
Relation		$\alpha_a = 2\alpha_\ell$	$\alpha_v = 3\alpha_\ell$

- ***Show that the coefficient of volume expansion for ideal gas is reciprocal of temperature***

Proof : Ideal Gas Equation is

$$PV = PV = \mu RT \text{ .... } (1)$$

At constant pressure

$$P\Delta V = \mu R\Delta T \text{ .... } (2)$$

Dividing the equations we get

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

$$\frac{\Delta V}{V\Delta T} = \frac{1}{T} = \alpha_V$$

- **Obtain the following relations**

$$\text{(i) } \alpha_a = 2\alpha_\ell \qquad \text{(ii) } \alpha_v = 3\alpha_\ell$$

Consider a cube of length ' l '. Due to the increase in temperature ' ΔT', length of cube increases by Δl in all directions. The Coefficient of linear expansion is

$$\alpha_\ell = \frac{\Delta\ell}{\ell\Delta T}$$

(i)Increase in area of cube ΔA = Final area - initial area $= (\ell+\Delta\ell)^2 - \ell^2 = 2\times\ell\times\Delta\ell$ [Neglecting $\Delta\ell^2$]

Area expansivity

$$\alpha_a = \frac{\Delta A}{A\Delta T} = \frac{2\ell\times\Delta\ell}{\ell^2\Delta T} = \frac{2\cdot\Delta\ell}{\ell\cdot\Delta T} = 2\cdot\alpha_\ell$$

Therefore, $\alpha_a = 2\cdot\alpha_\ell$

(ii) Due to ' ΔT ' the increase in volume of cube, $\Delta V = (\ell+\Delta\ell)^3 - \ell^3$

$= 3\ell^2\Delta\ell$

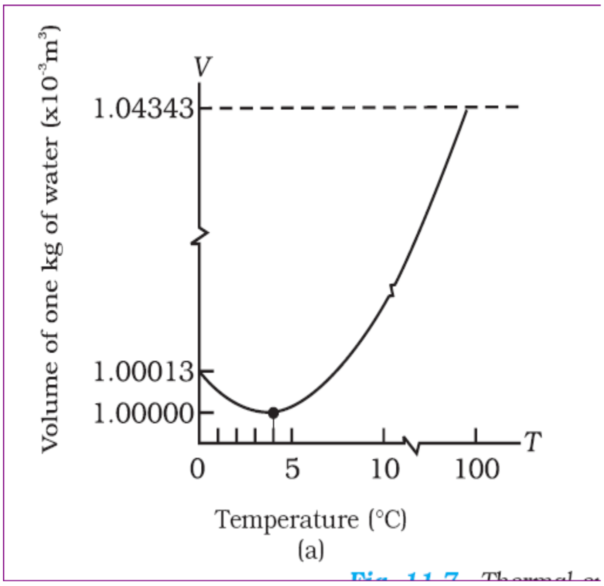
[Neglecting $\Delta\ell^2$ & $\Delta\ell^3$]

$$\alpha_v = \frac{\Delta V}{V\cdot\Delta T} = \frac{3\ell^2\cdot\Delta\ell}{\ell^3\times\Delta T} = 3\times\alpha_\ell$$

Therefore, $\alpha_v = 3\alpha_\ell$

ANOMALOUS BEHAVIOUR OF WATER

- **Water exhibits an anomalous behaviour; it contracts on heating between 0 °C and 4 °C.**
- **The volume of a given amount of water decreases as it is cooled from room temperature, until its temperature reaches 4 °C.**
- **This means that water has a maximum density at 4 °C.**



Environmental effect of Anomalous Behaviour of water

- **Bodies of water, such as lakes and ponds, freeze at the top first.**
- **As a lake cools toward 4 °C, water near the surface becomes denser and sinks; the water near the bottom rises.**
- **once the colder water on top reaches temperature below 4 °C, it becomes less dense and remains at the surface and freezes**
- **If water did not have this property, lakes and ponds would freeze from the bottom up, which would destroy much of their animal and plant life**

HEAT CAPACITY

- ***Heat capacity of a substance is the quantity of heat requried to raise the temperature of the substance through one kelvin.***

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

- **where ΔQ *is the amount of heat supplied to* the substance to change its temperature from T to $T + \Delta T$**

SPECIFIC HEAT CAPACITY

- ***Specific heat of a substance is the quantity of heat requried to raise the temperature of unit mass of the substance through one kelvin.***

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

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

Molar Specific Heat capacity (C)

- ***It is the amount of heat energy required to raise the temperature of one mole of a substance through one degree celsius or one kelvin.***

$$C = \frac{S}{\mu} = \frac{1}{\mu}\frac{\Delta Q}{\Delta T}$$

- **The SI unit of molar specific heat capacity is J mol^{-1} K^{-1}.**

Molar specific heat at constant volume (C_V)

- ***Molar specific heat of a gas at constant volume is the amount of heat required to raise the temperature of one mole of the gas through 1K when its volume is kept constant***

Molar Specific heat at constant pressure (C_P)

- ***Molar specific heat of the gas at constant pressure is defined as the amount of heat required to***

  raise the temperature of one mole of the gas through 1K, when its pressure is kept constant.

CALORIMETRY

- **Calorimetry means measurement of heat.**
- **When a body at higher temperature is brought in contact with another body at lower temperature, the heat lost by the hot body is equal to the heat gained by the colder body, provided no heat is allowed to escape to the surroundings.**
- **The device in which heat measurement can be made is called a calorimeter.**
- **It consists a metallic vessel and stirrer of the same material like copper or alumiunium.**

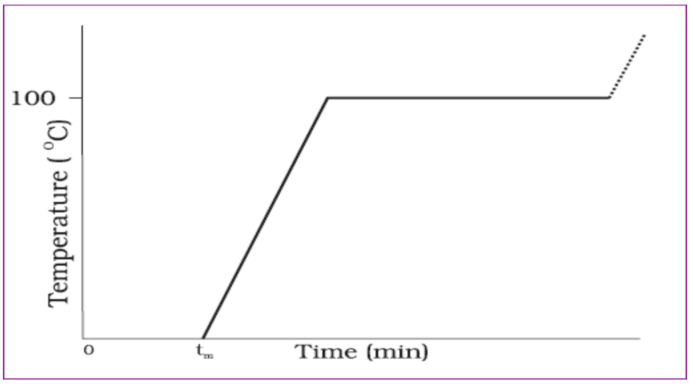
CHANGE OF STATE

- A transition from one state (solid, liquid or gas) to another state is called change of state.

Change of state	Name of
Solid $\rightarrow$ Liquid	Melting
Liquid $\rightarrow$ gas	Vapouri
Liquid $\rightarrow$ solid	Fusion
Solid $\rightarrow$ gas (without forming liquid)	Sublima

- During change of state, the two different state ***coexist in thermal equilibrium***.

Temperature – time graph of ice



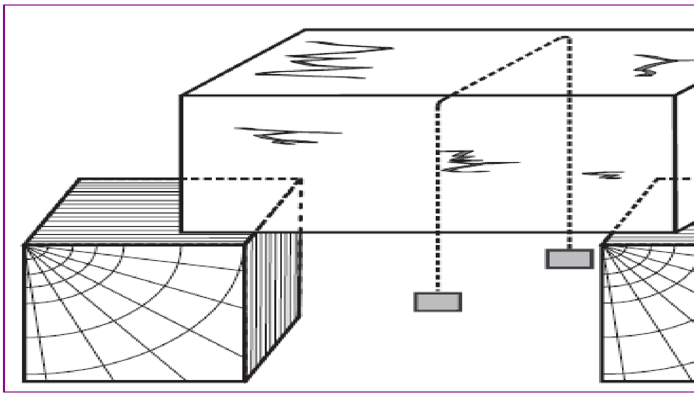
Melting point

- The temperature at which solid and liquid coexist in thermal equilibrium with each other is called melting point.
- The ***melting point decreases with pressure***

Boiling point

- The temperature at which liquid and vapour state of substance coexist in thermal equilibrium with each other is called boiling point.
- The ***boiling point increases with increase in pressure*** and it decreases with decrease in pressure

Regelation



- When a metal wire loaded at both ends is kept over an ice block, it passes through the ice block to the other side without splitting it.
- The melting point of ice just below the wire decreases due to increase in pressure.
- As ice melts wire passes and refreeze (due to decrease in pressure). This process is called regelation.

- ***Cooking is difficult at high altitude. Why ?***
  - At high altitude, pressure is low. Boiling point decreasess with decrease in pressure.

- ***For cooking rice pressure cooker is preferred. Why ?***
  - In pressure cooker, boiling point of water is increased by increasing pressure. Thus rice can be cooked at high temperature.

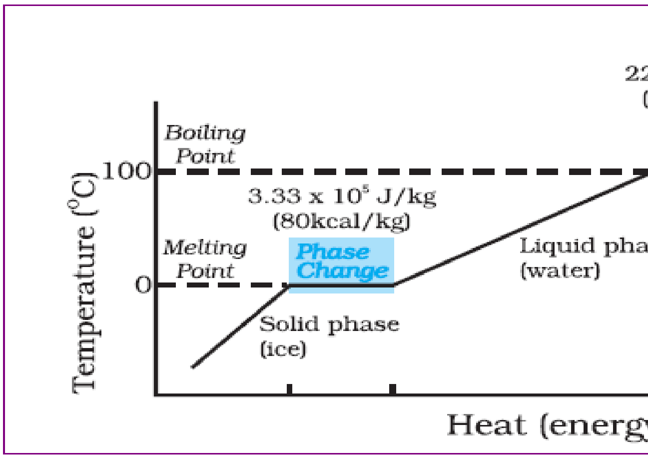
- ***You might have observed the bubbles of steam coming from bottom of vessel when water is heated.These bubbles disappear as it reaches top of liquid just before boiling and they reach the surface at the time of boiling. Explain the reason ?***
- Just before boiling, the bottom of liquid will be warm and at the top, liquid will be cool. So the bubbles of steam formed at bottom rises to cooler water and condense, hence they disappear. At the time of boiling, temperature of entire mass of water will be 100OC. Now the bubbles reaches top and then escape.

LATENT HEAT

- *The amount of heat per unit mass transferred during change of state of substance is called latent heat of substance for the process*
- *If mass m of a substance undergoes a change from one state to the other, then the quantity of heat required is given by*

$$Q = mL$$
$$\text{or} \quad L = Q/m$$

- Latent heat is characteristic of substance and it depends on pressure.
- Its unit is JKg^{-1}.
- The latent heat for a solid - liquid state change is called the ***latent heat of fusion (L_f)***, ***and that for a liquid-gas state change*** is called the ***latent heat of vaporisation (L_v).***

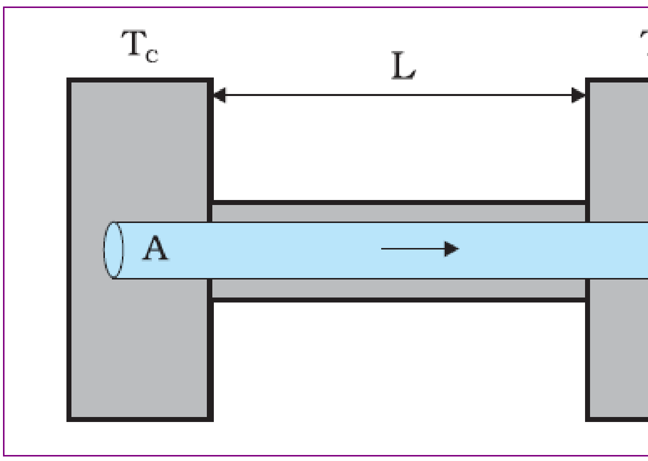


- ***Burns from steam are usually more serious than boiling water. Why ?***
  - Latent heat of vapourisation for water is $22.6 \times 10^5 J\ Kg^{-1}$ (. ie; $22.6 \times 10^5 J$ heat is required to convert 1 kg of water into steam at 100^0C). So at 100^0C, steam carries 22.6×10^5 J. (more heat than water).

HEAT TRANSFER

Conduction

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



- ***The rate of flow of heat (or heat current) H is proportional to the temperature difference***

($T_C - T_D$) and the area of cross section A and is inversely proportional to the length L **:**

$$H = KA\frac{T_C - T_D}{L}$$

- The constant of proportionality *K is called the* **thermal conductivity** of the material.
- **The greater the value of *K for a material, the more* rapidly will it conduct heat.**
- **The SI unit of *K is* J s^{-1} m^{-1} K^{-1} or W m^{-1} K^{-1}.**

Some cooking pots have copper coating on its bottom. Why ?

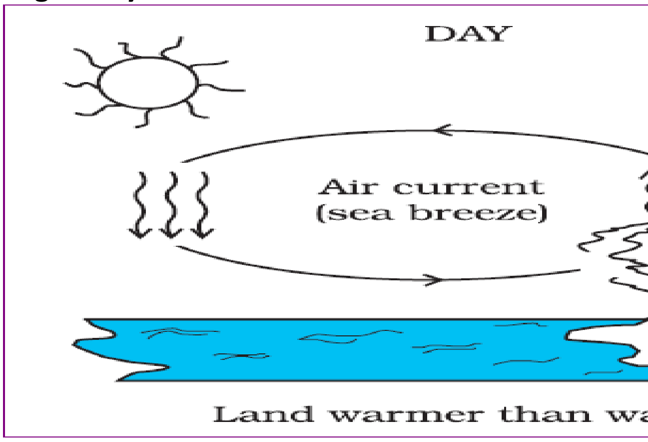
- Because of high thermal conductivity of copper, it distributes heat over the bottom of pot very fastly and promotes uniform cooking.

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.
- In natural convection when fluid is heated, it expands and becomes less dense. It then rises up and colder part replaces it. This process goes on as a cycle.
- In forced convection, material is forced to move by pump or by other physical means. Some examples are cooling system of automobile engines, heart that circulate blood throughout our body.

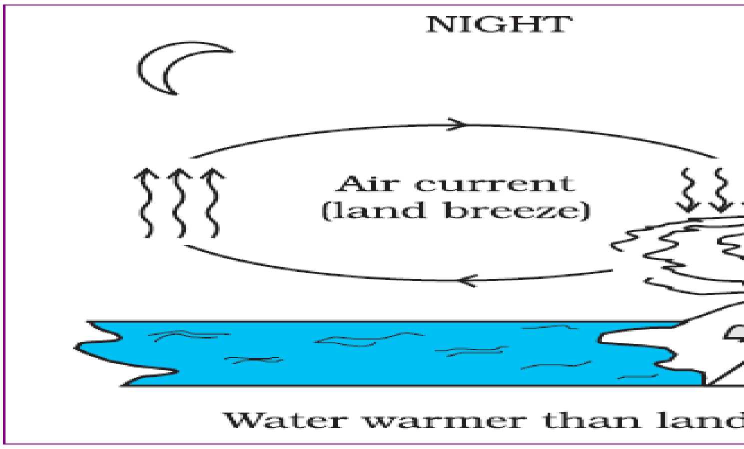
Sea breeze

- **Wind from sea to land on day time**
- **During the day, the ground heats up more quickly than large bodies of water**
- **The air in contact with the warm ground is heated by conduction and expands, becoming less dense than the surrounding cooler air.**
- **As a result, the warm air rises (air currents) and other air moves (winds) to fill the space-creating a sea breeze near a large body of water.**



Land breeze

- **Wind from land to sea on night**
- **At night, the ground loses its heat more quickly, and the water surface is warmer than the land**
- **Thus a land breeze is set up.**



Radiation

- In radiation, energy is transferred in the form of ***electromagnetic radiation*** called heat radiation.
- It requires ***no medium*** for heat transfer
- Earth receives energy from sun by means of radiation.

Thermal radiation :

- ***The electromagnetic radiation enitled by a body by virtue of its temperature is called thermal radiation***
- When this thermal radiation falls on other bodies, it is partly reflected and partly absorbed.

- The amount of heat that a body can absorb by radiation depends on the colour of the body.
- ***Black bodies*** absorb and emit radiant energy better than bodies of lighter colours.
- We ***wear white or light coloured clothes*** in summer so that they ***absorb the least heat*** from the sun.
- During ***winter, we use dark coloured*** clothes which absorb heat from the sun and keep our body warm.
- ***The bottoms of the utensils for cooking food are blackened*** so that they ***absorb maximum heat*** from the fire and give it to the vegetables to be cooked**.**

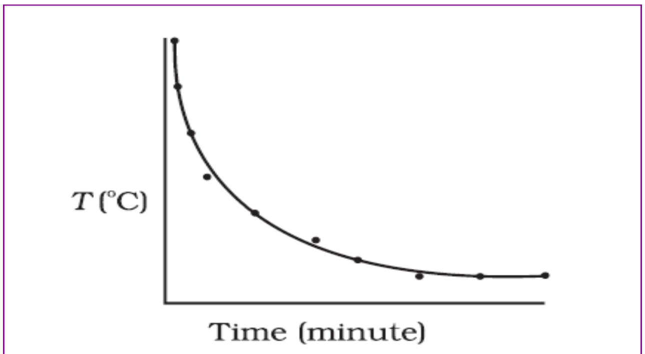
NEWTON'S LAW OF COOLING

- The rate of loss of heat is directly proportional to difference of temperature between the body and its surroundings.
- **The loss of heat by radiation depends upon the nature of the surface of the body and the area of the exposed surface.**

$$-\frac{dQ}{dt}=k(T_2 - T_1)$$

- **where *k is a positive constant depending upon* the area and nature of the surface of the body.**

Curve showing cooling of hot water with time



*****