Conduction.

The process of transmission of heat energy in which the heat is transferred from one particle to other particle without dislocation of the particle from their equilibrium position is called conduction.

(i) Conduction is a process which is possible in all states of matter.

(ii) In solids only conduction takes place.

(iii) In non-metallic solids and fluids the conduction takes place only due to vibrations of molecules, therefore they are poor conductors.

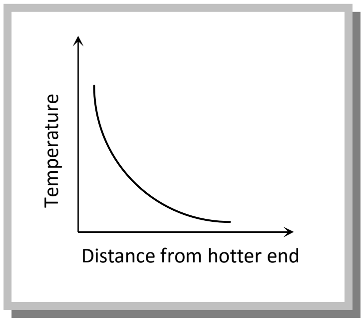
(iv) In metallic solids free electrons carry the heat energy, therefore they are good conductor of heat.

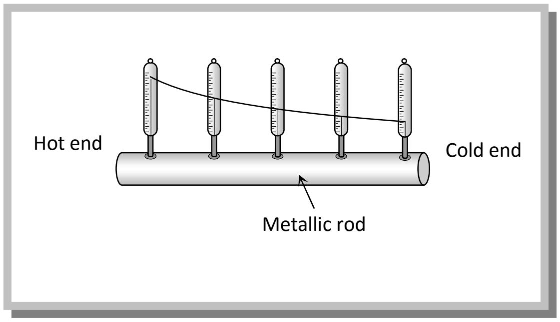
(1) Variable and steady state

When one end of a metallic rod is heated, heat flows by conduction from the hot end to the cold end.

In the process of conduction each cross-section of the rod receives heat from the adjacent cross-section towards the hot end. A part of this heat is absorbed by the cross-section itself whose temperature increases, another part is lost into atmosphere by convection & radiation and the rest is conducted away to the next cross-section.

Because in this state temperature of every cross-section of the rod goes on increasing, hence rod is said to exist in variable state.





After sometime, a state is reached when the temperature of every cross-section of the rod becomes constant. In this state, no heat is absorbed by the rod. The heat that reaches any cross-section is transmitted to the next except that a small part of heat is lost to surrounding from the sides by convection & radiation. This state of the rod in which no part of rod absorbs heat is called steady state.

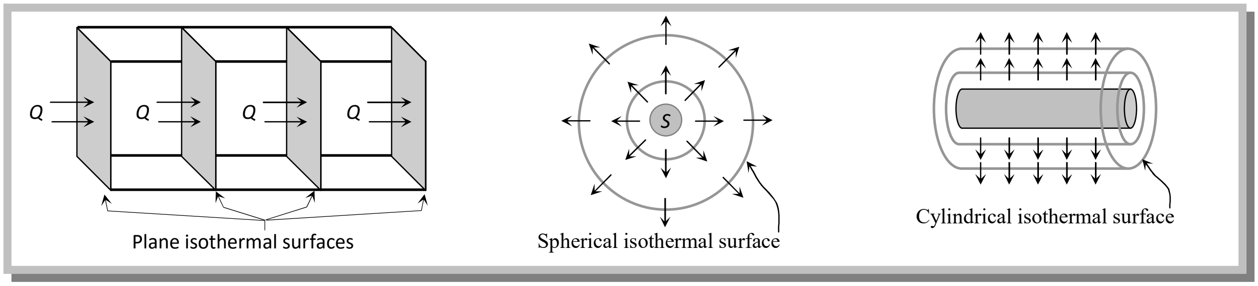
(2) Isothermal surface

Any surface (within a conductor) having its all points at the same temperature, is called isothermal surface. The direction of flow of heat through a conductor at any point is perpendicular to the isothermal surface passing through that point.

(i) If the material is rectangular or cylindrical rod, the isothermal surface is a plane surface.

(ii) If a point source of heat is situated at the center of a sphere the isothermal surface will be spherical,

(iii) If steam passes along the axis of the hollow cylinder, heat will flow through the walls of the cylinder so that in this condition the isothermal surface will be cylindrical.



Plane isothermal surfaces

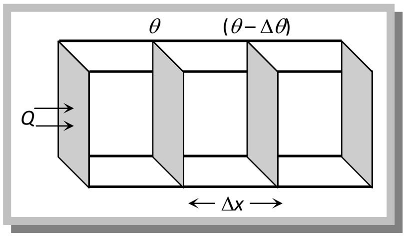
Spherical isothermal surface

Cylindrical isothermal surface

(3) Temperature Gradient

The rate of change of temperature with distance between two isothermal surfaces is called temperature gradient.

If the temperature of two isothermal surfaces be θ and $(\theta - \Delta\theta)$, and the perpendicular distance between them be Δx then Temperature gradient = $\frac{(\theta - \Delta\theta) - \theta}{\Delta x}$ = $\frac{-\Delta\theta}{\Delta x}$



The negative sign show that temperature θ decreases as the distance x increases in the direction of heat flow.

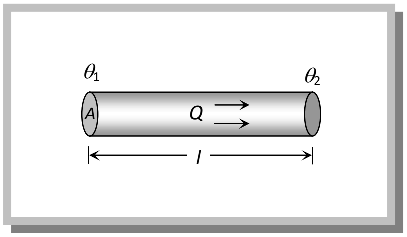
Unit: K/m (S.I.) and Dimensions: $[L^{-1}\theta]$

(4) Coefficient of thermal conductivity

If L be the length of the rod, A the area of cross-section and θ1 and θ2 are the temperature of its two faces, then the amount of heat flowing from one face to the other face in time t is given by

$$Q = \frac{KA(\theta_1 - \theta_2)t}{l}$$

Where K is coefficient of thermal conductivity of material of rod. It is the measure of the ability of a substance to conduct heat through it.



If A = 1m2, (θ1 – θ2) = 1oC, t = 1 sec and l = 1m, then Q = K.

Thus, thermal conductivity of a material is the amount of heat flowing per second during steady state through its rod of length 1 m and cross-section 1 m2 with a unit temperature difference between the opposite faces.

(i) Units: Cal/cm-sec oC (in C.G.S.), kcal/m-sec-K (in M.K.S.) and W/m- K (in S.I.)

(ii) Dimension: $[MLT^{-3}\theta^{-1}]$

(iii) The magnitude of K depends only on nature of the material.

(iv) For perfect conductors, $K = \infty$ and for perfect insulators, $K = 0$

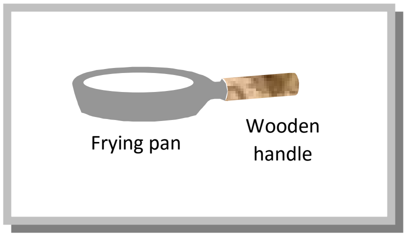
(v) Substances in which heat flows quickly and easily are known as good conductor of heat. They possesses large thermal conductivity due to large number of free electrons. Example: Silver, brass etc.

(vi) Substances which do not permit easy flow of heat are called bad conductors. They possess low thermal conductivity due to very few free electrons. Example: Glass, wood etc.

(vii) The thermal conductivity of pure metals decreases with rise in temperature but for alloys thermal conductivity increases with increase of temperature.

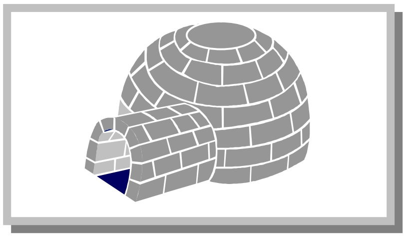
(viii) Human body is a bad conductor of heat (but it is a good conductor of electricity).

(5) Applications of conductivity in daily life



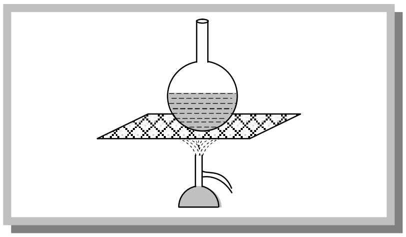
(i) Cooking utensils are provided with wooden handles, because wood is a poor conductor of heat. The hot utensils can be easily handled from the wooden handles and our hands are saved from burning.

(ii) We feel warmer in a fur coat. The air enclosed in the fur coat being bad conductor heat does not allow the body heat to flow outside. Hence we feel warmer in a fur coat.



(iii) Eskimos make double walled houses of the blocks of ice. Air enclosed in between the double walls prevents transmission of heat from the house to the cold surroundings.

For exactly the same reason, two thin blankets are warmer than one blanket of their combined thickness. The layer of air enclosed in between the two blankets makes the difference.



(iv) Wire gauze is placed over the flame of Bunsen burner while heating the flask or a beaker so that the flame does not go beyond the gauze and hence there is no direct contact between the flame and the flask. The wire gauze being a good conductor of heat, absorb the heat of the flame and transmit it to the flask.

Davy's safety lamp has been designed on this principle. The gases in the mines burn inside the gauze placed around the flame of the lamp. The temperature outside the gauze is not high, so the gases outside the gauze do not catch fire.

(v) Birds often swell their feathers in winter. By doing so, they enclose more air between their bodies and the feathers. The air, being bad conductor of heat prevents the out flow of their body heat. Thus, birds feel warmer in winter by swelling their feathers.

(6) Relation between temperature gradient and thermal conductivity

In steady state, rate of flow of heat $\frac{dQ}{dt} = -KA\frac{d\theta}{dx}$ = – KA (Temperature gradient)

If $\frac{dQ}{dt}$ is constant then temperature gradient $\propto \frac{1}{K}$

Temperature difference between the hot end and the cold end in steady state is inversely proportional to K, i.e. in case of good conductors temperature of the cold end will be very near to hot end.

In ideal conductor where K =∞, temperature difference in steady state will be zero.

(7) Wiedmann-Franz law

At a given temperature T, the ratio of thermal conductivity to electrical conductivity is constant i.e., $(K/\sigma T)$ = constant, i.e., a substance which is a good conductor of heat (e.g., silver) is also a good conductor of electricity. Mica is an exception to above law.

(8) Thermometric conductivity or diffusivity

It is a measure of rate of change of temperature (with time) when the body is not in steady state (i.e., in variable state)

The thermometric conductivity or diffusivity is defined as the ratio of the coefficient of thermal conductivity to the thermal capacity per unit volume of the material.

Thermal capacity per unit volume = $\frac{mc}{V}$ = ρc (As ρ is density of substance)

∴ Diffusivity (D) = $\frac{K}{\rho c}$

Unit: m2/sec andDimension:$[L^2T^{-1}]$

(9) Thermal resistance

The thermal resistance of a body is a measure of its opposition to the flow of heat through it.

It is defined as the ratio of temperature difference to the heat current (= Rate of flow of heat)

Now, temperature difference = $(\theta_1 - \theta_2)$ and heat current, H = $\frac{Q}{t}$

∴ Thermal resistance, $R = \frac{\theta_1 - \theta_2}{H} = \frac{\theta_1 - \theta_2}{Q/t} = \frac{\theta_1 - \theta_2}{KA(\theta_1 - \theta_2)/l} = \frac{l}{KA}$

Unit: $^oC \times sec/cal$ or $K \times sec/kcal$ and Dimension:$[M^{-1}L^{-2}T^3\theta]$