Modes of Heat Transfer

What is Heat?

Heat is a form of energy. It makes a substance hotter. We cannot see heat. We can only feel it by the effect of hotness it produces. We can define heat as energy in transit.

heat transfer definition :-

Since we know that heat is thermal energy in transit. Heat transfer is also referred to as heat. Here thermal energy moves from one place to another by virtue of the difference in temperature. Heat is the energy that is transferred from one body to another due to the temperature difference between the two bodies. With the definition of heat transfer or heat in mind, we now move on to know more about heat transfer.

Modes of Heat Transfer

There are three modes of heat transfer. Heat transfer or transmission of heat from one place to another takes place by three different ways that are:

1. Conduction
2. Convection and
3. Radiation

In solids, heat passes from one point to another through conduction. In Liquids and gases, heat transfer takes place by convection. Heat transfer takes place by the process of radiation when there are no particles of any kind which can move and transfer heat. So, in an empty space or vacuum heat is transferred by radiation. We shall now study heat transfer by conduction, convection, and radiation in detail.

What is conduction

If we heat one end of a metal bar by keeping it over a gas burner, we find that its other end also gets hot after some time. So heat is transferred from hot end of the bar to its cold end. In this case of heat transfer, there is no movement of molecules (or particles) of the material of metal bar as shown below in the figure.

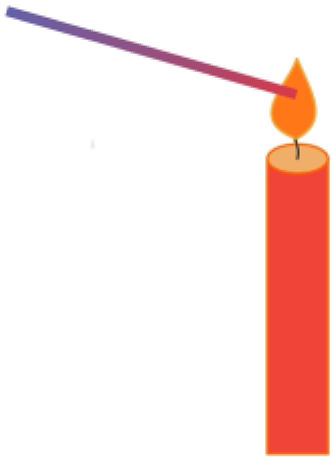


Figure 1 : Heat Transfer in metal bar by Conduction

Definition of Conduction

“Conduction is the transfer of heat from the hotter part of the material to its colder part without the actual movement of the particles. What I want to say here is that in the process of conduction there is no net movement of the particles of the body. Heat passes through solids by conduction only.

Thermal conduction plays an important role in our daily life. Some of the practical applications of thermal conduction include:-
(a) Cooking utensils are provided with wooden handles.
(b) Eskimos make double walled houses of the blocks of ice.
Learn more about heat conduction and thermal conductivity.

Convection involves the bodily movement of the heated molecules. Convection is the process in which heat is transmitted from one place to other by the actual movement of heated particles. It is prominent in the case of liquids and gases. Land and sea breezes are formed due to convection. It also plays an important part in ventilation, electric lamps, and heating of buildings by hot water circulation. The figure below shows the transfer of heat by convection when water in a cooking pot is heated.

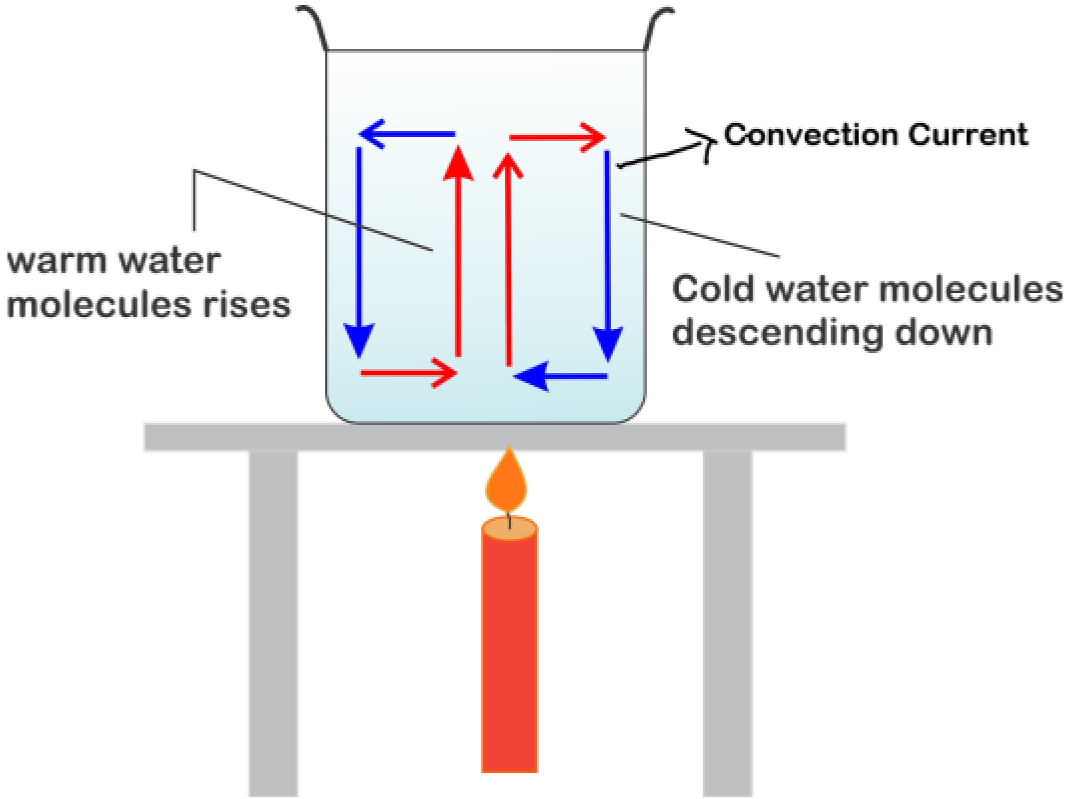


Figure 2 : Heat Transfer in water by convection

From this figure, you can clearly see convection current. So, when water is heated in a cooking pot then its heated molecules become lighter and moves upwards. As heated molecules of water move upwards, the denser and colder molecules of water begin to move downwards. So warm water rises and colder molecules of water descend. This sets up convection current as shown in the above figure. Learn more about Heat convection.

Radiation

Radiation is the process in which heat is transmitted one place to other directly without intervening medium. We get radiation of sun without an intervening medium. Heat radiations can pass through a vacuum. Their properties are similar to light radiations. Heat radiations also form a part of electromagnetic spectrum. Transfer of heat by radiation does not need any material medium. Energy from the sun comes to us by radiation.

Points to remember about heat transfer through conduction, convection, and radiation

1. Heat transfer through conduction is a slow process.
2. Heat transfer through convection is a rapid process
3. Out of these three processes radiation is the fastest one.
4. Radiation is the fastest because in this case, the transfer of heat takes place at the speed of light.
5. Both conduction and convection need a material medium for the transfer for heat.
6. Again consider the figure 2 that shows heating of water in a pot. Here In this process, all three modes of heat transfer can be seen.
    i. Pot is kept over the burner. In this case, heat is transferred by conduction

ii. Water in the pot transfers heat by convection
iii. If you place your hand at a short distance from the burner, you can feel its heat on your hand. This means burner is transferring heat to the hand by radiation.

Thermal conductivity definition

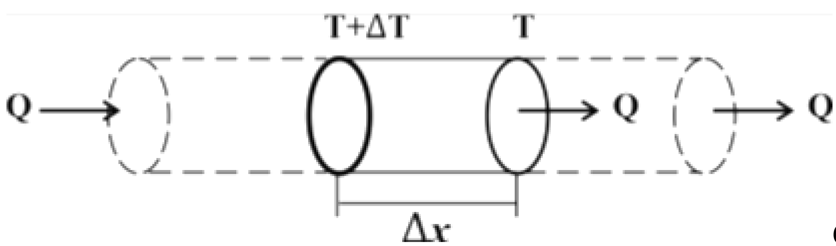
Thermal conductivity of a solid is a measure of the ability of the solid to conduct heat through it.

Greater is the thermal conductivity of a solid, the greater is its ability to conduct heat through it. If a solid has lower heat conductivity its ability to conduct heat through it would be lower.
The rate of heat conduction through a medium depends on following factors :-

- geometry of the medium,
- its thickness, and
- the material of the medium.
- It also depends on the temperature difference across the medium.

Thermal Conductivity Derivation

In this section we would have a look at how we can derive **Thermal Conductivity equation** or **Thermal conduction equation**.
Let us consider a piece of material made in the form of a bar of thickness Δx and area of cross-section A as shown below in the figure.



Consider this figure for the derivation of Thermal Conductivity equation where we have considered a piece of material made in the form of a bar of thickness Δx and area of cross-section A

From this figure we can see that Δx is the perpendicular distance between two isothermal plane surfaces. These two isothermal surfaces temperatures $(T+\Delta T)$ and T. Note that $(T+\Delta T)>T$.
Now the heat that flows perpendicular to the faces for a time t is measured. The experiment for measuring heat is repeated with other bars of same material but with different values of Δx and A. the results of such experiments show that, for a given value of ΔT

i. The quantity of heat conducted is directly proportional to the area of each surface i.e., $Q \propto A$

ii. Quantity of heat conducted is directly proportional to the temperature gradient in direction of heat flow. That is

i. $Q \propto -\Delta T \Delta x$
Provided both ΔT and Δx is small.
ii. Quantity of heat conducted is directly proportional to the time t i.e., $Q \propto t$

Combining all together we get the relation (1) $Q \propto -A \Delta T \Delta x \cdot t (1) \Rightarrow Q = -KA\ \Delta T \Delta x \cdot t$

This relation is mathematical expression for the basic low of heat conduction and is known as Fourier's law of heat conduction . It is also known as **thermal conduction equation**.

Here factor K is the proportionality constant and is known coefficient thermal conductivity of the material. Its value depends on the nature of material used. Thermal conductivity is the property of the material and it is the ability of the substance to transfer heat.
If in above equation (1) we put $A=1m2$, $\Delta x=1m$, $\Delta T=-1K$ and t=1sec $t=1sec$ then,
$Q=K$
The value of thermal conductivity determines the quantity of heat passing per unit area at a temperature drop of 1k per unit length in unit time.

We know that The quantity Q/t is the time rate of heat flow (i.e., heat flow per second) from the hotter face to the colder face and is at right angles to the faces [Unit = W (watt)].
So, $Qt=-KA\ \Delta T \Delta x$ If the area of cross-section is not uniform or if the steady state conditions are not reached, the equation can be applied to a thin layer of material normal to the direction of flow of heat. This could be a limiting case where $\Delta x \rightarrow 0$.
Due to this limiting case rate of heat flow that is given by
$H=dQdt=-KAdTdx$
Where dQ is the amount heat crossing the thin layer of thickness dx in time dT. dT is the temperature difference across the layer of thickness dx.

Units of dimensions of coefficient of thermal conductivity

Units of thermal conductivity

$K=Q \Delta x A (\Delta T) t$
K is =J.mm2K·s= $=J.mm2K \cdot s=Js-1m-1=wm-1k-1$
CGS unit of K is $Cal \cdot s-1cm-10C-1$

Dimensions of thermal conductivity

Dimensions of thermal conductivity K are $= \frac{[ML^2T^{-2}]\cdot[L]}{[L^2]\cdot[K]\cdot[T]} = [MLT^{-3}K^{-1}]$