Modes of heat transfer

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Modes of heat transfer

Heat may be transferred from one point to another in three different ways

- Conduction
- Convection
- Radiation

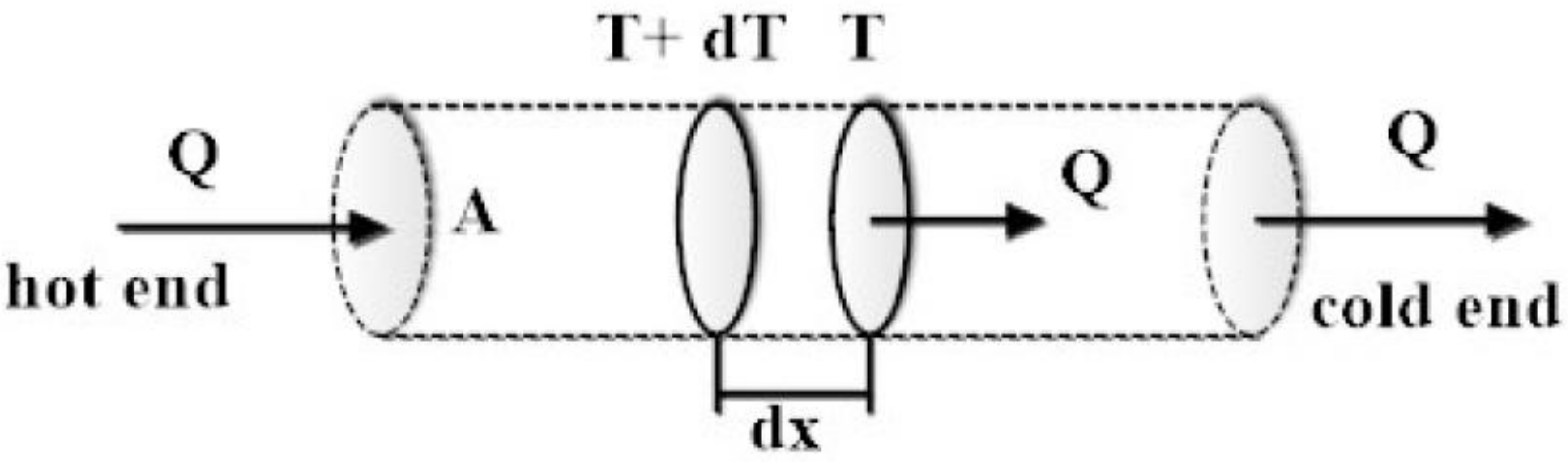
Conduction

- If one end of a metal rod is heated, the temperature of the other end gradually increases. Heat is transferred from one end of the rod to the other end. This transfer takes place due to molecular collisions and there is no movement of particles.

Transfer of heat from one place to another or one end (hot end) to the other end (cold end) of the substance, without the actual movement of particles, is called conduction.

- Conduction is the slowest mode of heat transfer.
- Conduction is most significant in solids and less in liquids and gases, due to the space between molecules.
- Substances that conduct heat are called good conductors and which do not conduct are called poor conductors or insulators.

- Metals are good conductors whereas gases and nonmetals are poor conductors.
- Aluminium, gold, copper, silver are examples of conductors.
- Silver is the best conductor of heat.
- Asbestos, rubber, glass paper, etc. are examples of insulators.
- The ability of a material to conduct heat is measured by a quantity called thermal conductivity of the material(λ_k).
- The SI unit of λ_k is $Js^{-1}m^{-1}K^{-1}$or $Wm^{-1}K^{-1}$.
- Metals have a high value of thermal conductivity due to the presence of a large number of free electrons.



- Consider a metallic rod of the area of cross-section A. Suppose one end of the rod is heated and an amount of heat Q is conducted from the hot end to the cold end of the rod. Consider a small element of the rod of length dx and a temperature difference of dT exists between its ends. The quantity of heat flowing through the rod depends on its area of cross-section, temperature

gradient ($\frac{dT}{dx}$) and time (t) for which heat flows. It can be mathematically expressed as

$$Q \propto A\frac{dT}{dx}t$$

$$Q = \lambda_k A\frac{dT}{dx}t$$

Here the constant of proportionality λ_k is called the thermal conductivity of the material.

Practical applications of thermal conductivity

- Cooking utensils are made of metals and their handles are made of wood.

(This is because metals are good conductors of heat, while wood is a bad conductor of heat.)

- When we take a metal ice tray and a package of frozen food from the freezer of the refrigerator, the metal tray feels colder than the package.

(This is because metal is a good conductor of heat and it removes heat from our hands much faster.)

- Houses made of hollow brick walls are cooler than concrete walls.
- During winter birds swell their feathers.

(In doing so the air trapped between the feathers prevent the loss of heat from their body. This is because air is a poor conductor of heat.)

- Ice is packed in sawdust or gunny bags.

(This is because air trapped in them prevents loss of heat and so ice does not melt. Air is a poor conductor of heat.)

Convection

- Convection is the phenomenon in which heat is transferred from one place to another by the actual movement of the particles of a heated substance.
- The convection process is faster than conduction. Transfer of heat by convection mode takes place in liquids and gases.
- If we boil a kettle of water, the hot water molecules become less dense and move to the top surface. At the same time dense water molecules at the top move to the bottom. Thus, a convection current gets established and the entire water gets heated.
- The rate at which heat is transferred from the surface of the fluid is given by the relation

$$\frac{Q}{t} = hA\Delta T$$

where A is the surface area of fluid,
ΔT is the temperature difference between the fluid at the upper and lower surfaces
h is a constant called convection coefficient.
The value of h depends on the shape of the surface and whether the surface is horizontal or vertical.

- Convection is classified as natural convection and forced convection.
- Natural convection is a process in which fluid motion is generated due to differences in densities and temperature gradient.
- Forced convection is a convection process in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.).
- The main mechanism of heat transfer inside a human body is forced convection.
- The heart serves as the pump and blood as the circulating fluid. The heat from our body is lost to the atmosphere through all three processes –conduction, convection, and radiation. But our blood circulation system transports just the required amount of heat to maintain a constant body temperature

Radiation

- Radiation is the fastest mode of heat transfer which does not require a material medium.
- All bodies radiate energy in the form of electromagnetic waves.
- The energy transferred in this mode is often called thermal radiation.
- The type of radiation associated with the transfer of heat energy from one location to another location is often known as infrared radiation. This is because the wavelength range of thermal radiation is from 800 nm to 400 μm, which belongs to the infrared region.
- In the radiation process, a hot body emits thermal radiation in all directions. Emitted radiation travels through space and falls on another body. The body absorbs thermal radiation and gets heated up.
- The heat from the sun reaches the earth by radiation.

Basic properties of thermal radiations

a)They travel in straight lines with the speed of light ($3x10^8 m/s$)

b) A material medium is not necessary for propagation.

c) They do not heat the medium through which they are travelling.

d) They can be reflected and refracted just as light.

e) They also exhibit the phenomena like interference, diffraction, and polarization.

f) Thermal radiations have longer wavelengths than visible light.

Specific heat capacity of a substance

- The heat capacity of a body is the quantity of heat required to raise the temperature of the body by one kelvin.
- The amount of heat (Q)absorbed by a body depends on the mass of the body (m), change in temperature (ΔT), and nature of the material. Hence,

$$Q \propto m\Delta T$$

$$Q = Cm\Delta T$$

- where the constant C is called the specific heat capacity of the substance.
- The specific heat capacity of a substance is defined as the quantity of heat required to raise the temperature of the unit mass of a substance through one kelvin.

$$C = \frac{Q}{m\Delta T}$$

The SI unit of specific heat capacity is s $Jkg^{-1}K^{-1.}$

The specific heat capacity of water is about 4200 $Jkg^{-1}K^{-1}$.This means that it will take 4200 J of energy to raise the temperature of 1 kg of water by 1 degree kelvin or degree Celsius.

Applications

a) Substances having a small specific heat capacity can be quickly heated up to a higher temperature even though only a small amount of heat is supplied. Such materials are very useful in making cookware such as frying pans, pots, kettles, etc.

b) Sensitive thermometers also must be made from materials with small specific heat capacity so that they can detect and show a change in temperature quickly.

c) Substances that have a high specific heat capacity are suitable as a material for constructing kettle handlers, insulators, and oven covers because a high amount of heat will cause only a small change in temperature and the material won't get hot too fast.

d) Heat storage instruments are usually made of substances with a high specific heat capacity.

e) Water acts as an excellent cooling agent in engines due to its high specific heat capacity.

f) Water is also used in houses in cold climate countries because as it is heated up (boiled), it tends to retain heat and warm the house due to its high specific heat capacity.