HEAT TRANSFER

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Heat transfer

- Heat transfer is a type of energy transfer which takes place because of temperature difference. from one system to another.

Energy transfer
→ Heat transfer
→ Work transfer

- Heat transfer is thermal energy in transit because of spatial temp gradient.

Energy
→ Energy in storage
→ Energy in transit

- In thermodynamics we deal with

(i) amount of heat transfer and amount of work transfer as system goes from one state to another
(ii) only with the end states during a process.
(iii) equilibrium phenomenon.

In heat transfer we deal with

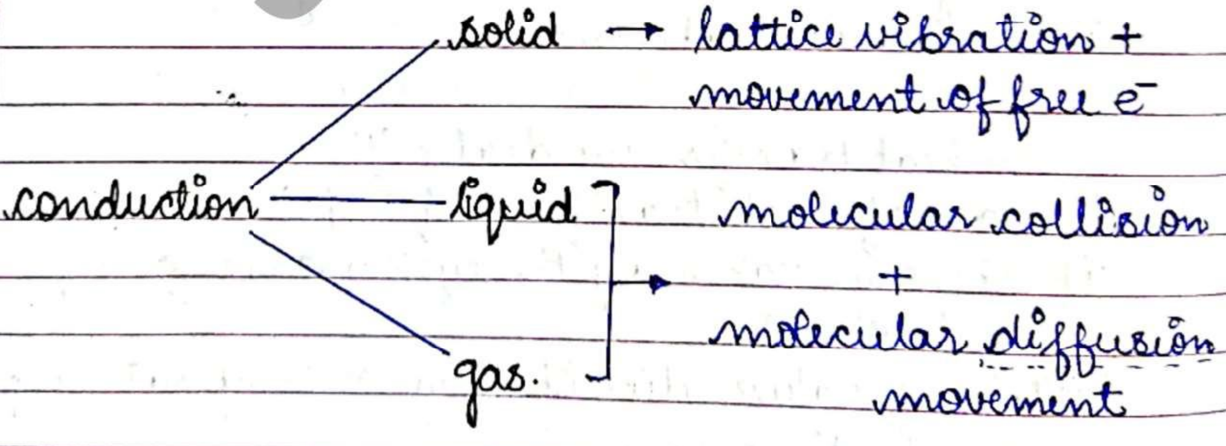
(i) rate of heat transfer ($\dot{q} \rightarrow J/s$)
(ii) the time taken by the system as it goes from state 1 to state 2.
(iii) the temperature distribution or temperature profile inside the system.
(iv) the mode of heat transfer (conduction, convection, radiation)
(v) non equilibrium position.

Note:
- Heat transfer is governed by second law of thermodynamics.
- Heat transfer will be from higher temperature to lower temperature.
- Heat transfer can not be measured only the effect of heat transfer can be observed or measured.
- Temperature difference is the driving potential for heat transfer.

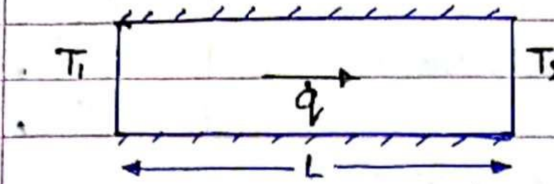
Modes of Heat transfer.

- **Conduction**: When heat transfer takes place because of temperature difference across the stationary medium then it is known as conduction. stationary medium can be solid or fluid.

- There is no bulk motion in conduction.



Fourier's law of heat conduction consider a rod with its lateral surface insulated.



A → cross sectional area of rod.
$\Delta T = T_1 - T_2$ → Temp differen

- It is based on experimental observation.

$\dot{q} \propto \Delta T$ (if A and L is constant) — (1)

$\dot{q} \propto \frac{1}{L}$ (if ΔT and A is constant). — (2)

$\dot{q} \propto A$ (if ΔT and L is constant). — (3)

combining (1),(2) and (3) we have

$$\dot{q} \propto A\frac{\Delta T}{L}$$

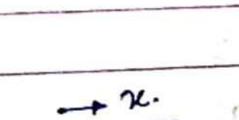
$$\dot{q} = \underset{\downarrow}{K}A\frac{\Delta T}{L}$$, $\dot{q}$ → heat transfer rate.

proportionality constant is known as thermal conductivity.

It can not be proved from first principle because it is based on experimental observations

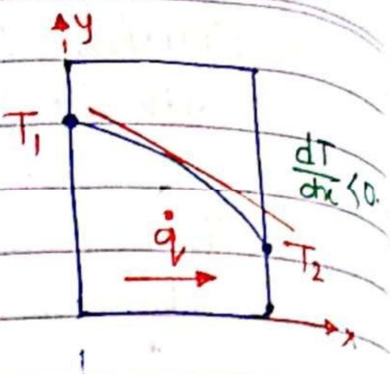
In the limiting case L → 0

$$\dot{Q} = -KA\frac{dT}{dx}$$

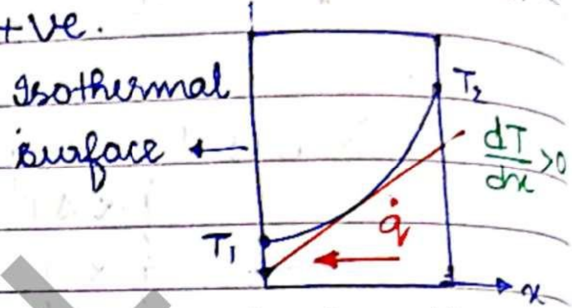


$dT = T_2 - T_1$

$$\dot{Q} = -KA\frac{dT}{dx} \quad (1-D)$$



- If $\frac{dT}{dx}$ is +ve, $\dot{Q}$ will be -ve.
- If $\frac{dT}{dx}$ is -ve, $\dot{Q}$ will be +ve.



$$\dot{Q} = -KA\frac{dT}{dx}$$
↓

-ve sign indicates that heat flows in the direction of decreasing temperature

$$q'' = \frac{\dot{Q}}{A} = -K\frac{dT}{dx}.$$
↓
heat flux ~~rate~~ heat transfer per unit area

- Heat transfer is a vector quantity (both magnitude and direction)

$$q''_x = -K\frac{dT}{dx}, \quad X\text{- component}$$

$K = K_x = K_y = K_z$

$$q''_y = -K\frac{dT}{dy}, \quad Y\text{- component}$$

↓
Isotropic material

$$q''_z = -K\frac{dT}{dz}, \quad Z\text{- component}$$

(position independent) $q'' = q''_x\hat{i} + q''_y\hat{j} + q''_z\hat{k}$

Homogeneous material $q'' = -K\frac{dT}{dx}\hat{i} - K\frac{dT}{dy}\hat{j} - K\frac{dT}{dz}\hat{k}$

↓ position independent.

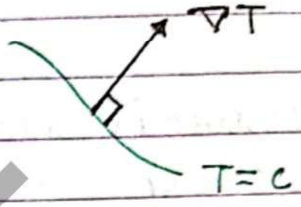
$q'' = -k(\nabla T)$ where $\nabla = \hat{i}\frac{\partial}{\partial x} + \hat{j}\frac{\partial}{\partial y} + \hat{k}\frac{\partial}{\partial z}$

$\frac{W}{m^2} \leftarrow \boxed{q'' = -k(\text{grad}\,T)}$ Fourier law for 3-D heat conduction

↓ homogeneous and isotropic

$T = T(x, y, z, t)$

Note: The direction of heat transfer is ⊥ to isothermal surface.



k → material property.

Thermal conductivity (k): Ability of material to conduct heat.

k↑ → heat conduction ↑

- **solid** → lattice vibration (k_{lv})
  → movement of free e^- (k_e)

$k = k_{lv} + k_e$

as temp ↑, lattice vibration ↑

∴ hinderance in movement of e^-

$k_{\text{pure metal}} >> k_{\text{alloy}}$

Thermal Conductivity (K) :

$\dot{q} = -K A \frac{dT}{dx}$ (Fourier,s law of heat Conduction)

K → Thermal Conductivity

- The thermal conductivity of a material is a measure of the ability of the material to conduct heat. A high value for thermal conductivity indicates that the material is a good heat conductor, and a low value indicates that the material is a poor heat conductor or insulator.

$K_{solid} > K_{liquid} > K_{gas}$

Mechanism of heat Conduction :

- In solids, heat conduction is due to two effects: the lattice vibration and the energy transported via the free flow of electrons.

$$K_{solid} = \underbrace{\boxed{K_e}}_{\text{Thermal Conductivity due to migration of free electron}} + \overbrace{\boxed{K_{l.v}}}^{\text{Thermal Conductivity due to lattice Vibration.}}$$

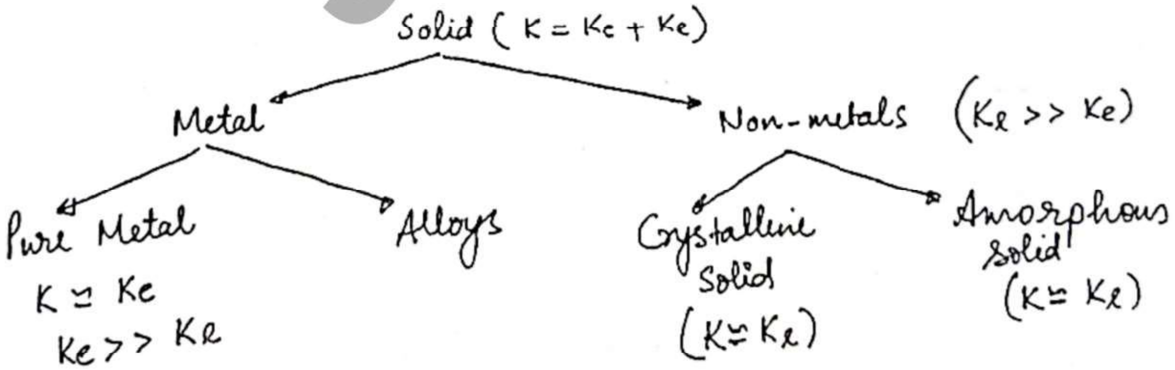
- The relatively high thermal conductivities of pure metals are primarily due to the free electron.

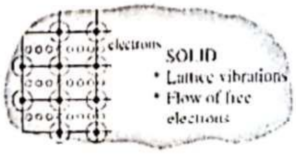
For pure metals $K_e >> K_{l.v}$

- For non-metallic Solid $K_e << K_{l.v}$

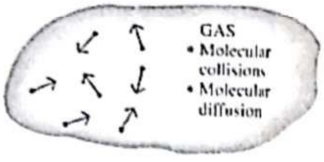
- Metals are good electrical and heat conductors because they have free electrons as well as lattice vibrations.
- Non-metals do not have free electrons, meaning they are electrically non-conducting materials. Crystalline solids such as diamond and semiconductors such as silicon are good heat conductors but poor electrical conductors. As a result, such materials find widespread use in the electronics industry. Despite their higher price, diamond heat sinks are used in the cooling of sensitive electronic components.

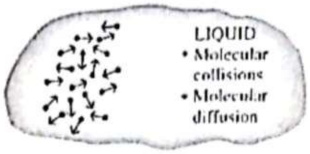
- $K_e \propto \frac{1}{\rho_e}$ where ρ_e → Electrical resitivity





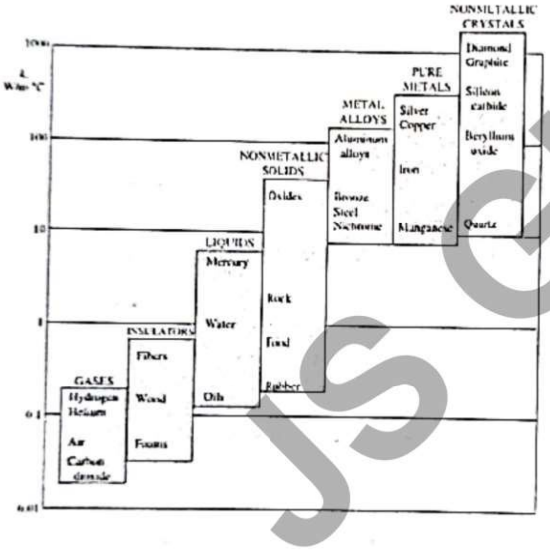
Mechanism of heat Conduction in liquids and Gases:





Note ⇨ ① Ksolid > Kliquid > Kgas

② Kpure metal > Kalloys (due to restriction in movement of e^-



The thermal conductivities of some materials at room temperature

Material	k, W/m · °C*
Diamond	2300
Silver	429
Copper	401
Gold	317
Aluminum	237
Iron	80.2
Mercury (l)	8.54
Glass	0.78
Brick	0.72
Water (l)	0.613
Human skin	0.37
Wood (oak)	0.17
Helium (g)	0.152
Soft rubber	0.13
Glass fiber	0.043
Air (g)	0.026
Urethane, rigid foam	0.026

Effect of temperature on thermal conductivity :

1. Solids:

- In the case of pure metals and alloys, the thermal conductivity predominantly depends on migration of free electron. As temperature increases, both number of free electrons and lattice vibrations increase. However, increased lattice vibrations obstruct the flow of free electrons through the medium. The combined effect of this phenomena, in most cases, results into decreased thermal conductivity with the increase in temperature, for the metals and alloys. There are some exceptions to this rule. For **Iron**, the thermal conductivity initially decreases and then increases slightly with an increase in temperature. For **Platinum**, the thermal conductivity increases with increase in temperature.

2. **Liquids :** Thermal conductivities of most liquids decreases with increasing temperature, with water being a notable exception. In the case of pure water, thermal conductivity first increases with increase in temperature and then starts decreasing.

Thermal conductivity of liquid is generally insensitive to pressure except near the thermodynamic critical point.