SHORT NOTES

CHAPTER

Heat Transfer

Available at:

9999021287

www.visualphysics.in

Rate of heat flow $= \dfrac{dQ}{dt}$ = Heat Current

Heat transfer

→ transfer of energy due to the presence of temperature difference

modes

Conduction

Heat transfer through the medium via energy transfer from particle to particle

$T_2 > T_1$

Convection

heat transfer from one part to other by motion of medium itself

hot water moves to transfer energy

Radiation

heat transfer using E-M waves

It do not need medium for energy transfer.

Variable state: when the variables (density, temperature etc) at a perticular point change with time

steady state: when the variables associated with a perticular point do not change with time.

i.e.

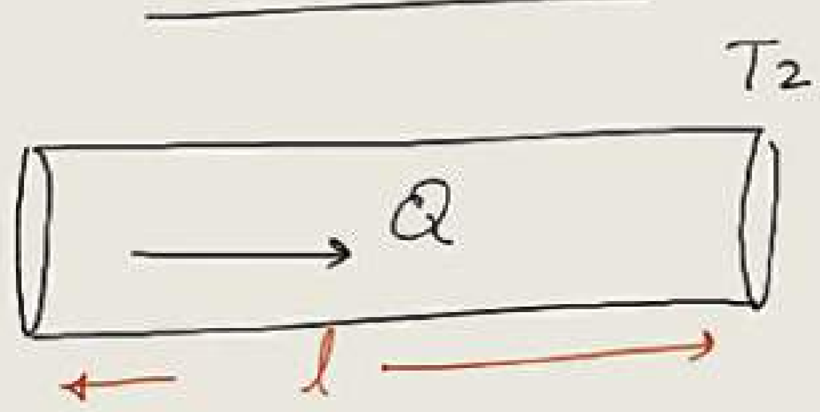
$$\left(\frac{\partial T}{\partial x}\right)_t \neq 0 \qquad \left(\frac{\partial T}{\partial t}\right)_t \neq 0$$

variable state

$$\left(\frac{\partial T}{\partial x}\right)_t = 0 \qquad \left(\frac{\partial T}{\partial t}\right)_t = 0$$

steady state

Conduction:



$\dfrac{dQ}{dt} = \dot{Q}$

$T_1 > T_2$

$\dot{Q} \propto A$ → Area of cross-section

$\dot{Q} \propto (T_1 - T_2)$ or ΔT → Temperature difference

$\dot{Q} \propto \frac{1}{l}$ → length

$\rightarrow \dot{Q} \propto \frac{A \Delta T}{l} \rightarrow \dot{Q} = \frac{K A \Delta T}{l}$

Thermal Conductivity → different for different material.

represent! Ability to conduct heat

$\dot{Q}$ → SI unit → $\frac{W}{m\,{}^\circ C}$

$\dot{Q} = H$ → Heat current

Analogy :-

Heat

$\dot{Q} = H$ = heat current

ΔT = Temperature difference

$H = \left(\frac{KA}{l}\right) \Delta T$

Electricity

$\frac{dq}{dt} = I$ = Current

ΔV = potential difference

$I = \frac{\Delta V}{R}$

$\Delta V \rightarrow \Delta T$

$I \rightarrow H$

$R \rightarrow \frac{l}{KA} = R_{Th}$

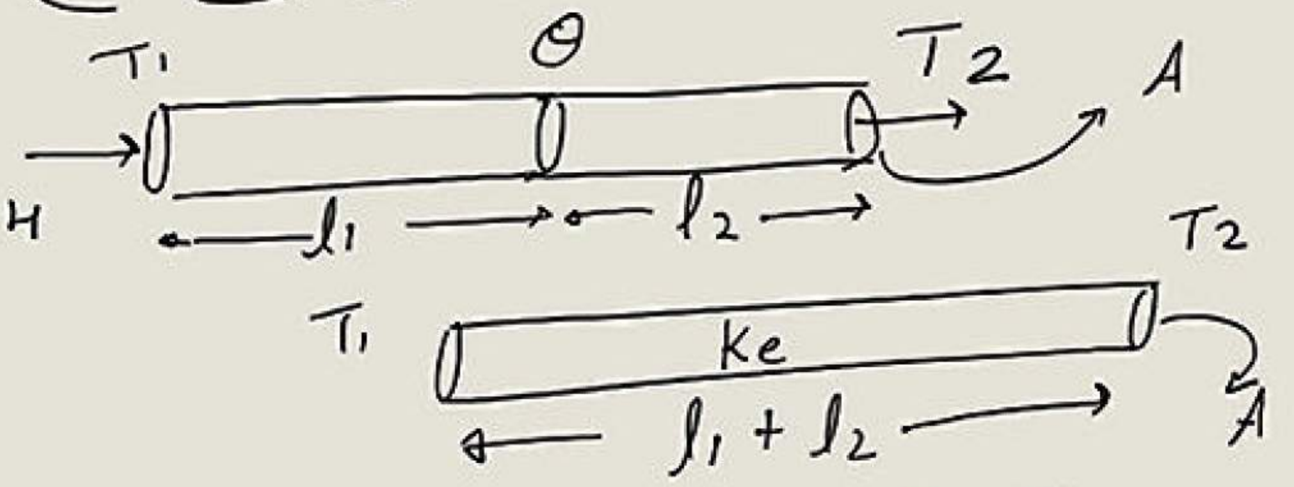
So we can say

$\rightarrow R_{TH} = \frac{l}{KA}$

Thermal resistance

Combination of Conductors :

Series Combination



$$H = \frac{T_1 - \theta}{R_1}, \quad H = \frac{\theta - T_2}{R_2}$$

$$T_1 - \theta = HR_1, \quad \theta - T_2 = HR_2$$

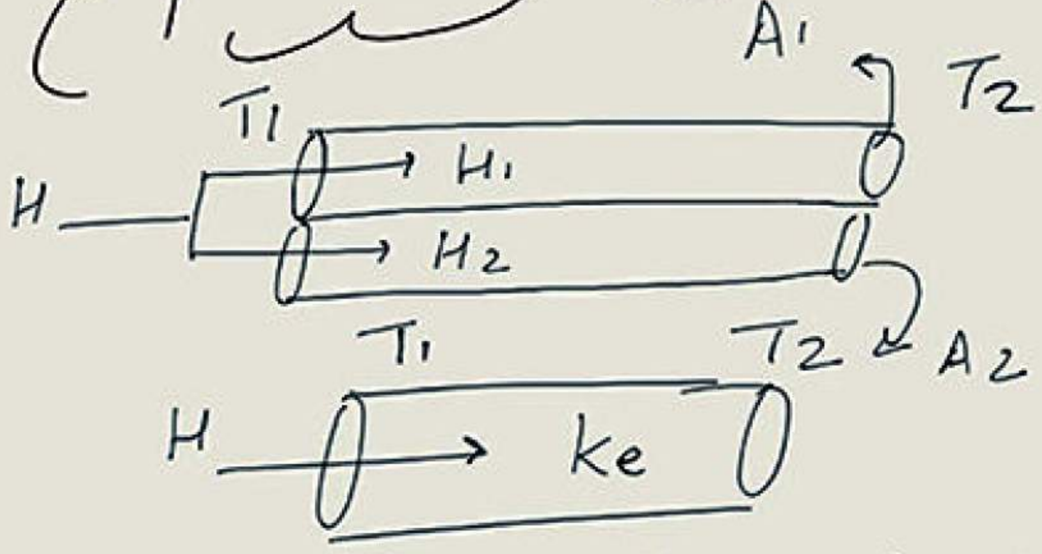
$$T_1 - T_2 = H\,R_{eq}$$

$$R_{eq} = R_1 + R_2$$

$$\frac{l_1 + l_2}{k_e} = \frac{l_1}{k_1} + \frac{l_1}{k_2}$$

$$k_e = \frac{l_1 + l_2}{\frac{l_1}{k_1} + \frac{l_2}{k_2}}$$

Parallel Combination



$$H_1 = \frac{T_1 - T_2}{R_1}, \quad H_2 = \frac{T_1 - T_2}{R_2}$$

$$H = H_1 + H_2 = \frac{T_1 - T_2}{R_{eq}}$$

$$\frac{T_1 - T_2}{R_{eq}} = \frac{T_1 - T_2}{R_1} + \frac{T_1 - T_2}{R_2}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{K_e(A_1 + A_2)}{l} = \frac{k_1 A_1}{l} + \frac{k_2 A_2}{l}$$

$$K_e = \frac{k_1 A_1 + k_2 A_2}{A_1 + A_2}$$

Radiation

Prevost's theory

- All body emits radiation at all temperature
- All body absorbs radiation at all temperature
- Amount of emission / absorbtion depends on temperature and material

$T_{surrounding} > T_{body}$

Absorbtion > Emission

⇒ Body temperature ↓

$T_{surrounding} < T_{body}$

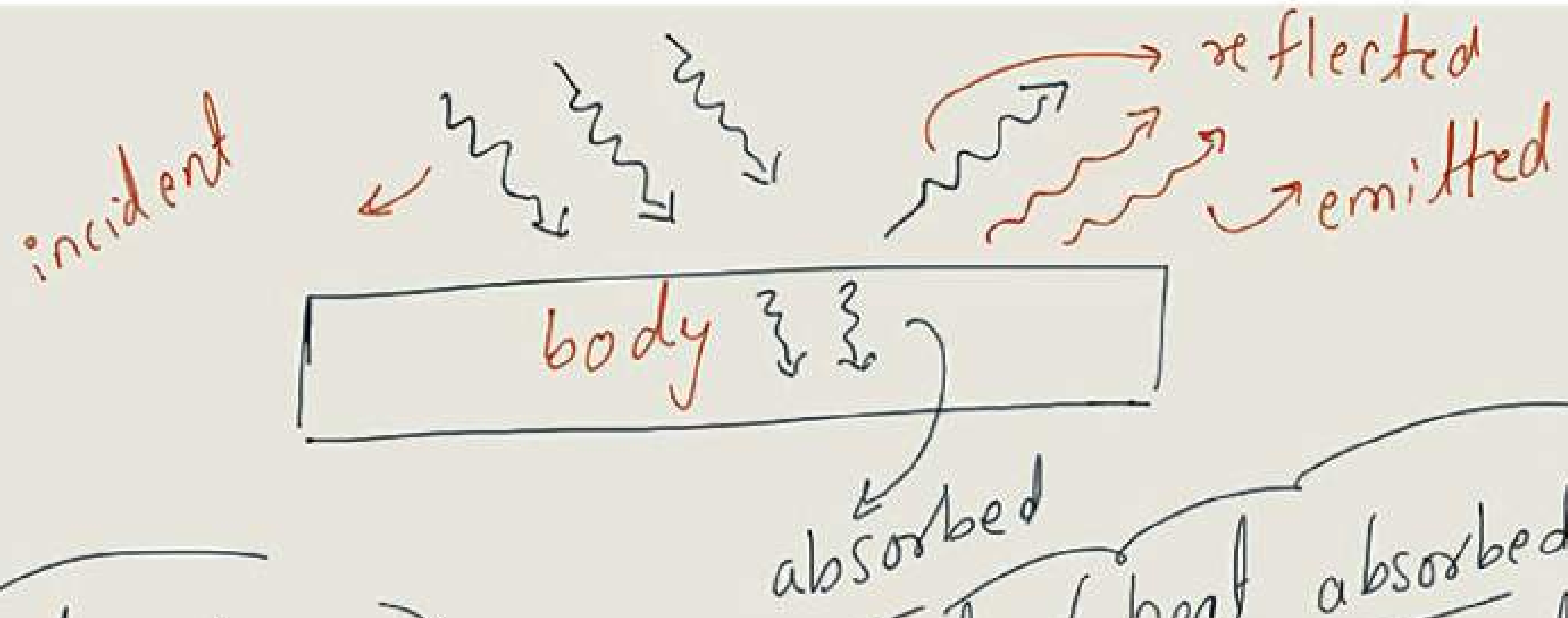
Absorbtion < Emission

body temperature ↑

Body temperature constant

$T_{surrounding} = T_{body}$

Emission = Absorbtion



Absorptive power (a) → $\dfrac{\text{Amount of heat absorbed}}{\text{Amound of heat incident}}$

Reflecting power (r) → $\dfrac{\text{Amount of heat reflected}}{\text{Amount of heat incident}}$

Transmitting power (t) → $\dfrac{\text{Amount of heat transmitted}}{\text{Amount of heat incident}}$

$a + r + t = 1$

emissive power (E) → $\dfrac{Q}{A\,t}$

Q → Heat emitted at given temperature

t → time

A → Area

Coefficient of emission = e → $\dfrac{E}{E_b}$

E → emissive power of body at 'T' (Temp)

E_b → emissive power of black body at 'T'

black body → An ideal body that absorbs all radiation falling on it

Emissive power depends on

- Material
- wavelength
- Temperature

E_λ → spectral emissive power [at given wavelength] similarly → $\{a_\lambda\}$ → spectral absorbtive power [at perticular wavelength of radiation]

for black body

↳ $\{a_\lambda = 1 \quad , \quad e_\lambda = 1\}$

* for a given condition, black body radiates / absorbs maximum amount of radiation.

{ practical black body

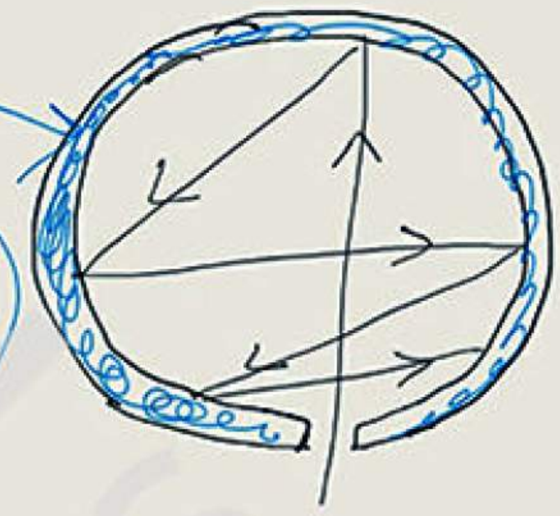
Lamp black (1% reflection)

Graphite (3% reflection)

platinum

Isothermal enclosure

(radiation is traped)



{ Kirch off's law → $\left\{\dfrac{E}{a} = E_b\right\}$ [for any substance]

↳ { true for any wavelength

OR

$$\left\{a = \frac{E}{E_b} = e\right\}$$

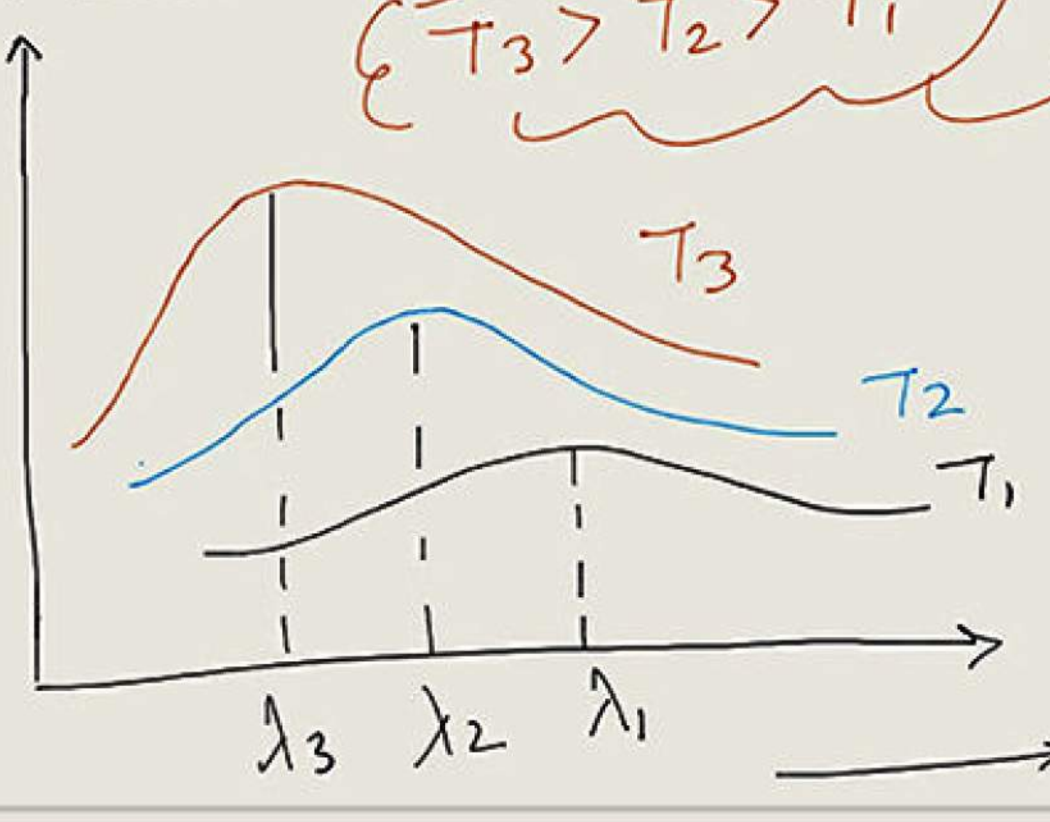
$$\left\{\frac{E_\lambda}{a_\lambda} = E_{\lambda b} = \text{Constant}\right\}$$

wein's displacement law: (Can be used to measure star's temp)

→ $\{\lambda_m$ = wavelength of maximum Radiation$\}$

$\{T_3 > T_2 > T_1\}$ → $(\lambda_3 < \lambda_2 < \lambda_1)$

$$E = \frac{Q}{A t}$$



$\{\lambda_m T = \text{Constant} = b\}$

↓ wein's displacement law

for black body

$\{b = 2.898 \times 10^{-3}\ m\text{-}K\}$

* $T_3 > T_2 > T_1$ → $I_3 > I_2 > I_1$

$\lambda_3 < \lambda_2 < \lambda_1$

Intensity of radiation

stefan's boltzman law:

for percftly black body

$I \propto T^4$

power radiated

$\dot{Q} = \sigma A T^4$

absolute Temperature (k)

rate of heat/radiation emission

Area

stefan's boltzman constan = universal constant $= 5.67 \times 10^{-8}\ W/m^2k^4$

for other material

$\dot{Q} = e\sigma A T^4$

$0 \leq e \leq 1$

power emitted

$e\sigma A T^4$

when surronding is at T_0

$\dot{Q}$ = net heat emitted $= e\sigma A(T^4 - T_0^4)$

power absorbed

$a\sigma A T_0^4 = e\sigma A T_0^4$ → $\because e = a$

Newton's law of cooling

if temperature difference between body and surrounding is less

$T - T_0 = \Delta T$ small

T = body's temperature

T_0 = surrounding temperature

Rate of cooling $\propto \Delta T$

rate of change of body temperat $\propto \Delta T$

$$\frac{dT}{dt} \propto \Delta T \qquad \frac{dT}{dt} \propto (T - T_0)$$

or $$\frac{dT}{dt} = k(T - T_0)$$

k = proportionality constant, depends on material & surrounding condition

derivation of Newton's colling

$$\dot{Q} = e\sigma A(T^4 - T_0^4)$$

$$mc\frac{dT}{dt} = e\sigma A(T^4 - T_0^4)$$

$$\frac{dT}{dt} = \left(\frac{e\sigma A}{mc}\right)(T^4 - T_0^4) \qquad T = T_0 + \Delta T$$

$$\Rightarrow \frac{dT}{dt} = \left(\frac{e\sigma A}{mc}\right)\left[(T_0 + \Delta T)^4 - T_0^4\right] = \left(\frac{e\sigma A\, T_0^4}{mc}\right)\left[\left(1 + \frac{\Delta T}{T_0}\right)^4 - 1\right]$$

$$\frac{dT}{dt} = \left(\frac{e\sigma A T_0^4}{mc}\right)\left[\left(1 + 4\frac{\Delta T}{T_0}\right) - 1\right], \text{ if } \left(\frac{\Delta T}{T_0} \ll 1\right)$$

$$\frac{dT}{dt} = \left(\frac{4e\sigma A T_0^4}{mc}\right)(\Delta T) = k[T - T_0]$$

$$k = \frac{4e\sigma A T_0^4}{mc}$$