MODE OF HEAT TRANSFER ...

Differences between conduction convenction and radiation :

Conduction	Convenction	Radiation
Heat transferred due to temperature difference between two ends of solid and liquid (Hg)	Heat transferred due to density difference between two ends in liquid and gases	Heat transferred due to electro-magnetic waves and propagate by all medium.
Heat transferred by the vibrational motion of medium particle and free electron (no actual motion)	Heat transferred by the actual motion of the medium particle from one place to another place	Medium is not required for the transmission It can transmit in vaccum also.
Slowest process	Slow process	Fastest Process (3×10^8 m/sec)
Irregular path	Irregular path	Straight line path (similar to light radiation)

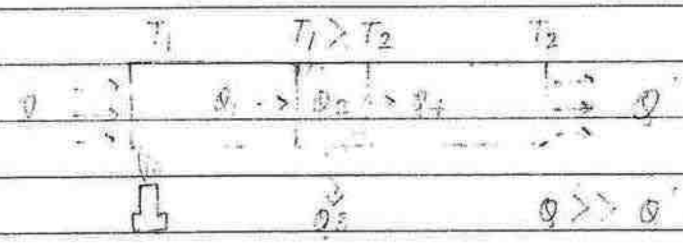
1. Conduction:

i) Energy is transferred due to temperature difference between the two ends of solid by the vibrational motion of the medium particle

ii) Heat transfer always from high temperature side to low temperature side from one particle to another particle.

Two states during conduction:

i) Variable state:



$$Q_1 = Q_2 + Q_3 + Q_4$$

and

$$Q_1 = Q_2 + Q_3 \quad (\text{when } Q_3 = 0 \text{ i.e insulated})$$

where,

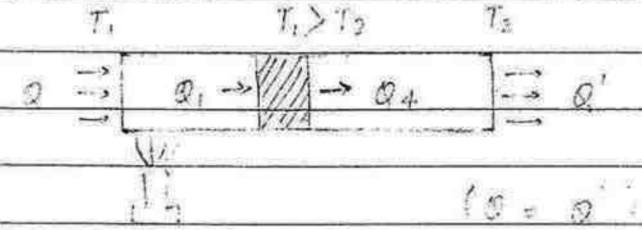
Q_1 = heat taken by the previous section

Q_2 = heat absorbed by the system

Q_3 = heat emmitted by cylindrical surface in the form of radiation or ~~convection~~. convenction

Q_4 = heat transferred to the next system

ii) ~~Static~~ Stedy State:



$Q_2 = Q_3 = 0$

$\therefore Q = Q_1 = Q_4 = Q'$

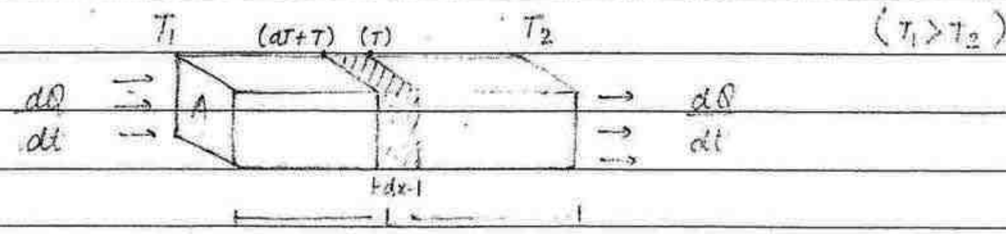
$\therefore E \propto I \propto \dfrac{1}{d^2}$ (intensity)

* In ~~static~~ stedy state heat absorption by any section is zero

* Temperature of different cross section is different and decreases in the direction of heat flow.

* Temperature of every one cross section ~~is different~~ remains constant but not same

Rate of heat flow:



$\because \dfrac{dQ}{dt} \propto A$

$$\frac{dQ}{dt} \propto K$$

$$\frac{dQ}{dt} \propto \frac{-dT}{dx}$$ rate of ↓ in temp per unit length

$$\therefore \frac{dQ}{dt} = \frac{-KA\,dT}{dx}$$

For uniform rod,

$$\frac{dQ}{dt} = \frac{-KA\,(T_2 - T_1)}{L}$$

M.P.T

$$\ast \quad \therefore \boxed{\frac{dQ}{dt} = \frac{KA\,(T_1 - T_2)}{L} = \frac{T_1 - T_2}{R}} \quad \left[\because R = \frac{L}{KA}\right]$$

where, A = cross section area
K = coefficient of thermal conductivity
(depends on property of material only)
L = length of the rod.

Order of K in metals:

$K_{silver} > K_{copper} > K_{gold} > K_{aluminium}$

$Ag > Cu > Au > Al$

Order of K in phase:

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

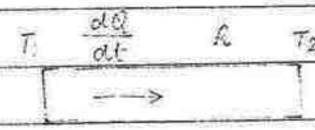
Unit of K : $\frac{\text{Joule}}{\text{m-sec K}}$ or $\frac{\text{watt}}{\text{mK}}$ $\left[\because K = \frac{dQ\,l}{dt\,A\,T}\right]$

dimensions: $[M^1 L^1 T^{-3} K^{-1}]$

temperature gradiant : $\frac{dT}{dx}$

Rate of fall in temperature with distance.

Comparision with electric current :

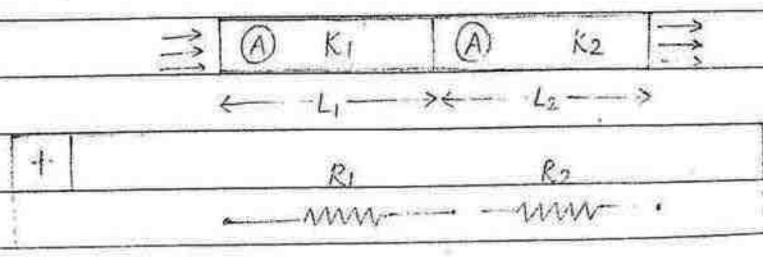


$V_1 - V_2 = i \times R$ [$\because V = IR$]	$T_1 - T_2 = \frac{dQ}{dt} \times \frac{L}{KA}$
• $\therefore$ $V_1 - V_2$ (voltage difference)	$\therefore$ $T_1 - T_2$ (Temperature difference)
• i	$\frac{dQ}{dt}$ = thermal current
• $R = \frac{\rho l}{A}$	$R = \frac{L}{KA}$ = thermal resistance

$$\therefore \boxed{\frac{dQ}{dt} = \frac{T_1 - T_2}{R}}$$

To calculate equivalent thermal conductivity.

i) Series combination :



$$\therefore \frac{L_1 + L_2}{K_{eq} A} = \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A}$$

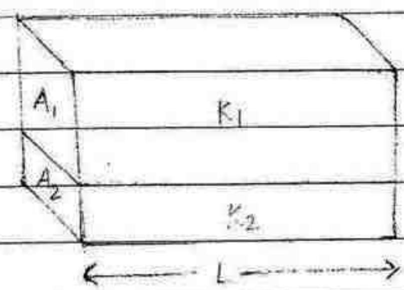
- For same cross section area:

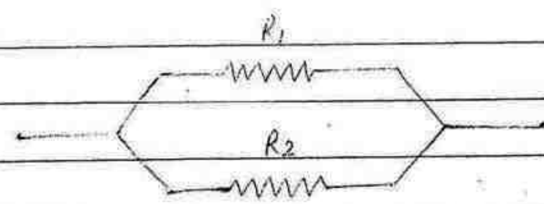
$$\boxed{K_{eq} = \frac{L_1 + L_2}{\frac{L_1}{K_1} + \frac{L_2}{K_2}} \qquad \therefore K_{eq} = \frac{\Sigma (L)}{\Sigma \left(\frac{L}{K}\right)}}$$

- If $L_1 = L_2 = L$ (same length):

$$\boxed{K_{eq} = \frac{2 K_1 K_2}{K_1 + K_2}}$$ Harmonic Mean (H.M)

ii) Parallel combination:





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

$$\therefore \frac{K_{eq}(A_1 + A_2)}{L} = \frac{K_1 A_1}{L} + \frac{K_2 A_2}{L}$$

$$\therefore \boxed{K_{eq} = \frac{K_1A_1 + K_2A_2}{A_1 + A_2}}$$

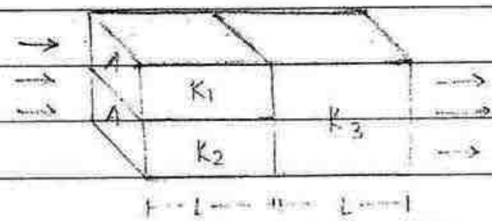
- For same length :

$$\boxed{K_{eq} = \frac{\Sigma (KA)}{\Sigma A}}$$

- If $A_1 = A_2 = A$ (same cross section area):

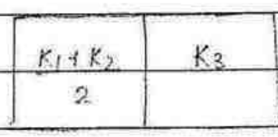
$$\therefore \boxed{K_{eq} = \frac{K_1 + K_2}{2}} \quad \text{Arithmetic Mean (AM)}$$

Q.1 Calculate thermal conductivity in the following combination:



$\because$ K_1 and K_2 are in parallel combination

$$\therefore K_{eq.} = \frac{K_1 + K_2}{2} \quad (A.M)$$

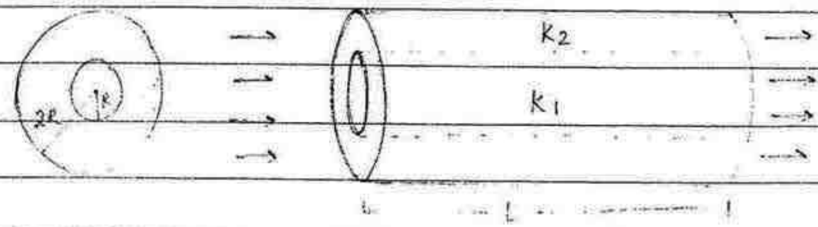


$\because$ $\frac{K_1+K_2}{2}$ and K_3 are in series combination

$$\therefore K_{eq} = \frac{2\left(\frac{K_1+K_2}{2}\right)K_3}{\frac{K_1+K_2}{2} + K_3} \quad (H.M)$$

$$= \frac{2K_3(K_1 + K_2)}{2K_3 + K_1 + K_2}$$

Q.2 Calculate equivalent thermal conductivity in the following combination:

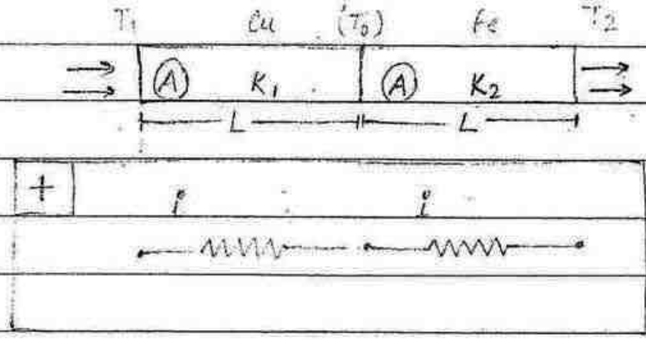


$$A_1 = \pi R^2$$
$$A_2 = \pi(2R)^2 - \pi R^2$$
$$= 4\pi R^2 - \pi R^2 = 3\pi R^2$$

$\because$ K_1 and K_2 are in parallel combination

$$\therefore K_{eq} = \frac{K_1 A_1 + K_2 A_2}{A_1 + A_2}$$
$$= \frac{K_1 \pi R^2 + K_2 (3\pi R^2)}{\pi R^2 + 3\pi R^2}$$
$$= \frac{\pi R^2 (K_1 + 3K_2)}{\pi R^2 (1+3)}$$
$$= \frac{K_1 + 3K_2}{4}$$

To calculate junction temperature:

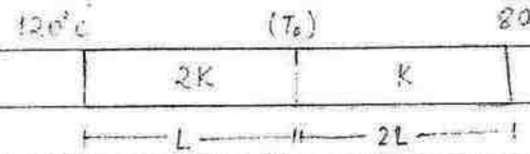


$$\therefore \left(\frac{dQ}{dt}\right)_{Cu} = \left(\frac{dQ}{dt}\right)_{Fe}$$

∵ Same rate of heat transfer :

★ $\therefore \boxed{\dfrac{K_1 A}{L_1}(T_1 - T_0) = \dfrac{K_2 A}{L_2}(T_0 - T_2)}$

Q. 3 Calculate the junction temperature.



$$\therefore \left(\frac{dQ}{dt}\right)_L = \left(\frac{dQ}{dt}\right)_{2L}$$

$$\frac{2KA}{L}(120 - T_0) = \frac{KA}{2L}(T_0 - 80)$$

$$240 - 2T_0 = \frac{1}{2}(T_0 - 80)$$

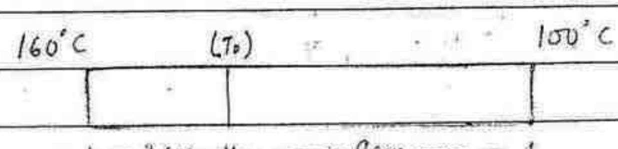
$$480 - 4T_0 = T_0 - 80$$

$$480 + 80 = 4T_0 + T_0$$

$$560 = 5T_0$$

$$\therefore T_0 = \frac{560}{5} = 112^\circ C$$

Q. 4 Calculate junction temperature of uniform rod ?



$$\therefore \left(\frac{dQ}{dt}\right)_3 = \left(\frac{dQ}{dt}\right)_9$$

$$= \frac{KA}{3}(160 - T_0) = \frac{KA}{9}(T_0 - 100)$$

$$= 3(160 - T_0) = \cancel{KA}(T_0 - 100)$$

$$480 - 3T_0 = T_0 - 100$$
$$480 + 100 = 3T_0 + T_0$$
$$580 = 4T_0$$
$$\therefore T_0 = \frac{580}{4} = 145^\circ C$$

OR

Short trick : Temperature gradiant

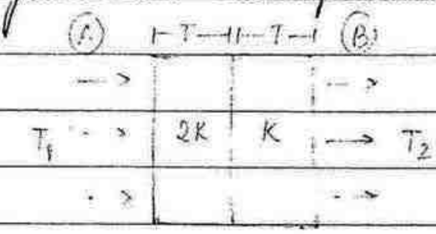
$$\frac{dT}{dx} = \frac{160-100}{12}$$
$$= \frac{60}{12} = 5^\circ c / cm$$

$\therefore$ Decrease in temperature in 3 sec

$$= 3 \times 5 = 15^\circ C.$$

$\therefore$ Temperature after 3 sec = $160^\circ - 15^\circ = 145^\circ C$

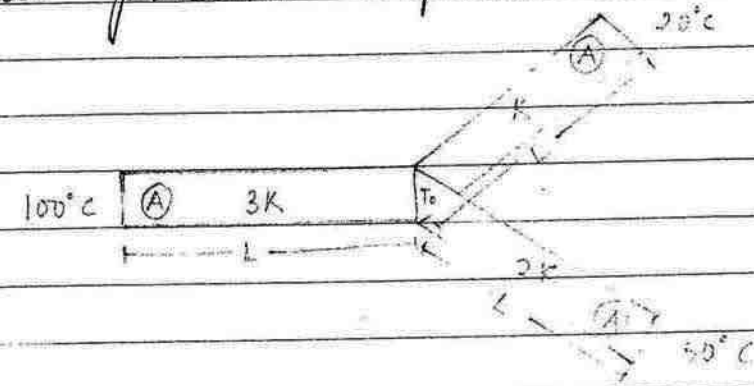
Q. 5 ~~calculate junction temperature :~~

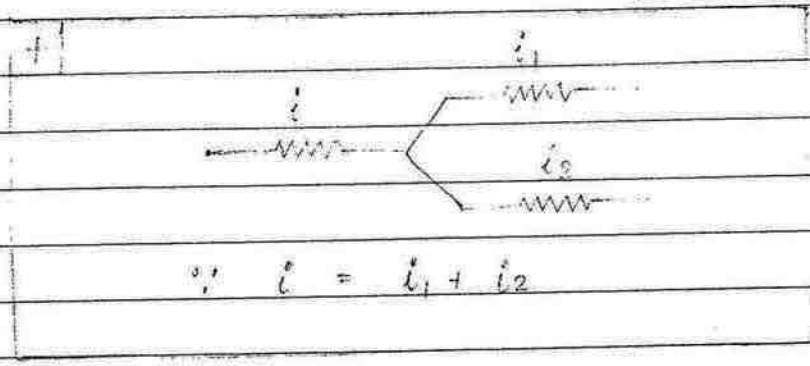


given : $T_1 - T_2 = 36^\circ c$. calculate $T_1 - T_0$.

$$\because \left(\frac{dQ}{dt}\right)_A = \left(\frac{dQ}{dt}\right)_B$$
$$= \frac{2KA}{T}(T_1 - T_0) = \frac{KA}{T}(T_0 - T_2)$$
$$2(T_1 - T_0) = T_0 - T_2$$
$$2T_1 - 2T_0 = T_0 - T_1 + 36 \quad (\text{given that } T_2 = T_1 - 36)$$
$$\therefore 2T_1 + T_1 = 2T_0 + T_0 + 36$$
$$3T_1 - 3T_0 = 36$$
$$\therefore T_1 - T_0 = 12^\circ C$$

Q. 6. Calculate junction temperature :





$\because \; i = i_1 + i_2$

$$\because \left(\frac{dQ}{dt}\right)_{3K} = \left(\frac{dQ}{dt}\right)_{K} + \left(\frac{dQ}{dt}\right)_{2K}$$

$$\frac{3KA}{L}(100 - T_0) = \frac{KA}{L}(T_0 - 20) + \frac{2KA}{L}(T_0 - 50)$$

$$300 - 3T_0 = T_0 - 20 + 2T_0 - 100$$

$$20 + 300 + 100 = T_0 \cancel{-20} + 2T_0 + 3T_0$$

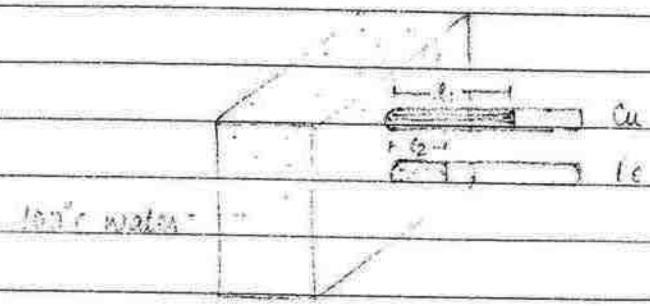
$$420 = 6T_0$$

$$\therefore T_0 = \frac{420}{6} = 70°C$$

Application of conduction :

i) Ingen horse experiment : It is used to compare the conductivity of different material

P.T.O.



$$\because \frac{dQ}{dt} \propto K$$

$$\therefore K \propto l^2$$

where l is the length of the melting wax.

$$\boxed{\left(\frac{K_{Cu}}{K_{Fe}}\right) = \left(\frac{l_1}{l_2}\right)^2}$$

* This experiment has to be used, whenever there is a coating of wax.

ii) Weidamann - Franz law: At a given constant temperature, the ratio of thermal conductivity and electrical conductivity remains constant

At constant temperature,

$$\frac{K}{\sigma} = \text{constant}$$

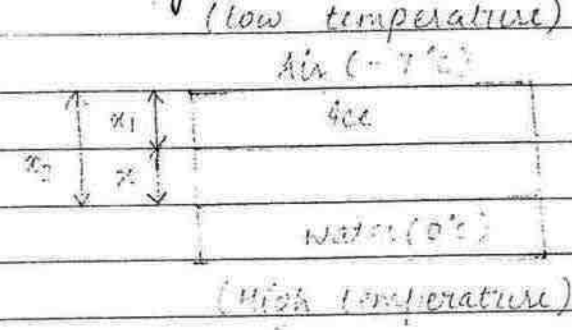
$$\therefore K \propto \sigma$$

where K = thermal conductivity
σ = electrical conductivity

It means that good conductor or heat is also a good conductor of electricity.

iii) Growth of ice on water surface:
MODULE 2 (Pg - 166)

Initially thin layer of ice formed on the water surface is explained by radiation and then growth of ice is explained by conduction.



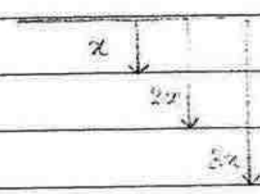
$$x_1 \xrightarrow{t} x_2$$

$$\therefore \quad \boxed{t = \frac{1}{2}\frac{\rho_{ice}\, L_{freezing}}{KT}\left(x_2^2 - x_1^2\right)}$$

- T should be in °C

Case I :

$$0^\circ \xrightarrow{t_1} x$$
$$0^\circ \xrightarrow{t_2} 2x$$
$$0^\circ \xrightarrow{t_3} 3x$$

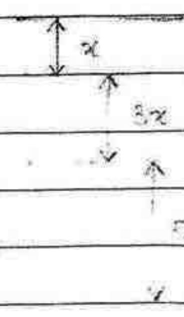


$$\therefore \; t \propto (x_2^2 - x_1^2)$$

$$t_1 : t_2 : t_3 = (x^2 - 0) : [(2x)^2 - 0] : [(3x)^2 - 0]$$
$$1 : 4 : 9$$

Case II :

$$0^\circ \longrightarrow x$$
$$x \longrightarrow 2x$$
$$2x \longrightarrow 3x$$

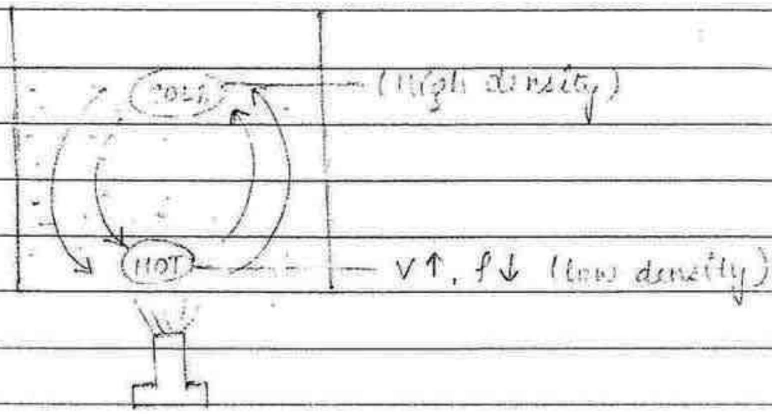


$$t_1 : t_2 : t_3 = (x^2 - 0) : [(2x)^2 - x^2] : [(3x)^2 - (2x)^2]$$
$$1 : 3 : 5$$

2. Convection:

i) Heat is transferred due to density difference in liquid and gas is known as convection.

ii) Heat transferred by the actual motion of medium particle from one place to another place.



iii) Convection based on gravity: convection is not possible in zero gravity.

- Regions of zero gravity: orbiting satellite. centre of the earth, free falling lift.

Q. 7 In weightlessness condition, liquid can be heated by:

i) Conduction (Bulk)
ii) Convection
iii) Radiation (affects the surface - hot)
iv) None of these

Ans) i) Conduction

Q-8 In weightlessness condition, liquid can be heated by :

i) conduction

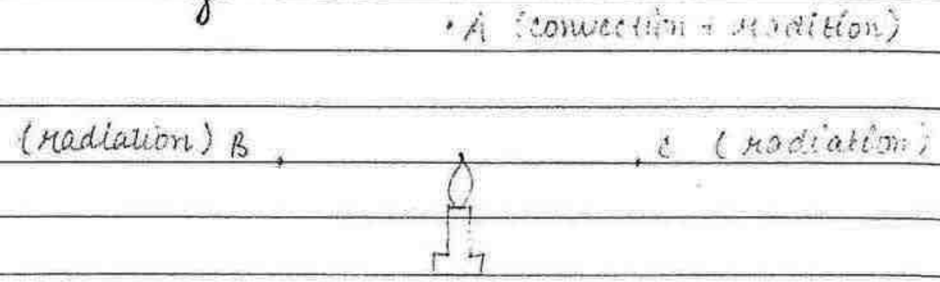
ii) convection

iii) radiation

iv) liquid can't be heated

Ans) iv) liquid can't be heated

iv) In convection, heat propagate by temperature gradiant exist in vertically upward direction not horizontal.



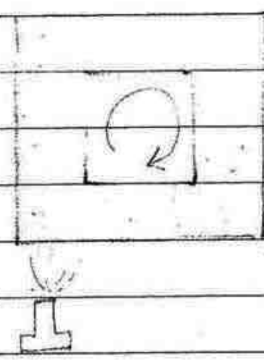
$\therefore T_A > T_B = T_C$

* Most of the heat transferred on the earth is by convection and the contribution of conduction and radiation is very small. (we feel hot due to convection)

Types of convection :

Natural convection	Forced convection
• It is also known as free convection	It is also known as artificial convection
• It is always in vertically upward direction	It's direction is based on force

• $\boxed{\dfrac{dQ}{dt} \propto (\theta - \theta_0)^{5/4}}$	$\boxed{\dfrac{dQ}{dt} \propto (\theta - \theta_0)}$
• $\frac{5}{4} = 1\frac{1}{2}$ power law [सवा घात का नियम]	equal power law [बराबर घात का नियम] It is equivalent to 'Newtons laws of ~~Putting~~' cooling'
eg: cold air flows from ocean to ground side in the day time and vice-versa	eg: circulation of blood in our body. eg: circulation of water around boiler.



3. Thermal Radiation:

MODULE 2 (Pg-151)

i) Spectrum of radiation is observed by KCl prism, Rock salt Prism and flourspar prism

ii) * Intensity of radiation is measured by Bolometer and Thermopile

iii) Pyrometer is used to measure high temperature only.
Range: Minimum : 800°C
Maximum : No limit

- Temperature of 'sun' and stars are measured by pyrometer.

Electromagnetic wave spectrum:
(By Maxwell's concept)

cosmic rays	γ-ray	x-ray	U.V rays	Visible light VIBGYOR	Infra-red Thermal radiation	Micro waves	Radio and TV waves

0   1Å   100Å   4000Å   7800Å 4×10^6 Å $\lambda \rightarrow$

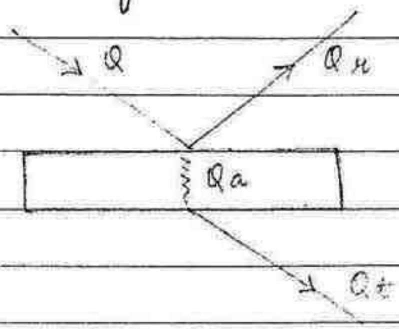
- wavelength range of radiations : 0 to ∞
- wavelength of heat radiations : 7800 Å to 4×10^6 Å (infra-red)
- width of visible region : 4000 Å
- The wavelength corresponding to maximum emission of radiation λ_m shifts from longer wavelength to shorter wavelength as the temperature ~~decreases~~ increases. Due to this the colour of the body appears to be changing.

$\xleftarrow{T\uparrow,\ \lambda_m\downarrow}$

V I B G Y O R

(4000 Å) (white) (7800 Å)

Nature of Surface :



$$\therefore \quad Q = Q_r + Q_a + Q_t$$

$$\frac{Q}{Q} = \frac{Q_r}{Q} + \frac{Q_a}{Q} + \frac{Q_t}{Q}$$

$$\therefore \quad \boxed{1 = r + a + t}$$

- For general body / grey body :
  $0 < r/t/a < 1$
- r, a and t are unitless.

where Q = amount of incident radiation
Q_r = amount of reflected radiation
Q_a = amount of absorbed radiation
Q_t = amount of transmit radiation

$\therefore \; r = \frac{Q_r}{Q}$ = Reflective power / reflective co-efficient

$a = \frac{Q_a}{Q}$ = absorptive power / absorptive co-efficient

$t = \frac{Q_t}{Q}$ = transmitive power / transmitive co-efficient.

Case I : when $r = \frac{Qr}{Q} = 1 \quad \therefore a = t = 0 \quad \therefore Q = Qr$

• perfectly reflective body

eg: Ideal Mirror.

Case II : when $a = \frac{Qa}{Q} = 1 \quad \therefore r = t = 0 \quad \therefore Q = Qa$

• perfectly absorptive body

eg: Ideal black bodies.

Case III : when $t = \frac{Qt}{Q} = 1 \quad \therefore a = r = 0 \quad \therefore Qt = Q$

• perfectly transmitive body.

eg: Vaccum.

* These three cases are practically not possible.

Q-9 Total 700 J is incident on the surface & 25 cal is transmitted. 45% is absorbed. Calculate amount of reflected radiations.

Transmitted radiations $= 25$ cal

$= 25 \times 4.2 = 105\ J\ (Qt)$

absorbed radiations $= \frac{45}{100} \times 700 = 315\ J\ (Qa)$

Incident radiations $= 700\ J\ (Q)$

$\because Q = Qa + Qt + Qr$

$\therefore Qr = Q - Qa - Qt$

$= 700 - 315 - 105$

$= 700 - 420$

$= 280\ J$

Q-10 Total 100 cal is incident on the surface. 120 J reflects and 20% is absorbed. then, calculate Transmitive power.

$$Q = 100 \text{ cal} = 100 \times 4.2 = 420 \text{ J}$$

$$Q_r = 120 \text{ J}$$

$$Q_a = \frac{20}{100} \times 420 = 84 \text{ J}$$

$$\because Q = Q_a + Q_r + Q_t$$

$$\therefore Q_t = Q - Q_a - Q_r$$

$$= \cancel{40}\ 420 - 84 - 120$$

$$= 420 - 204 = 216 \text{ J}$$

$$\therefore \text{transmitive power, } t = \frac{Q_t}{Q}$$

$$= \frac{216 \text{ J}}{420 \text{ J}} = 0.51$$

Some definitions:

i) Absorptive power (a): It is the ratio of amount of absorbed radiations and amount of incident radiations.

$$a = \frac{Q_a}{Q} = \frac{\text{Amount of absorbed radiation } (0 \text{ to } \infty)}{\text{Amount of incident radiation } (0 \text{ to } \infty)}$$

- It is unitless
- For general bodies (GB) : $0 < a < 1$
- For ideal black body (IBB) : $a = 1$
- It depends on nature of surface only

ii) Spectral Absorptive power (a_λ):

$a_\lambda = \frac{Q_{a\lambda}}{Q_\lambda} = \frac{\text{Amount of absorbed radiations from } \lambda \text{ Å}}{\text{Amount of incident radiations from } \lambda \text{ Å}}$

- It is unitless
- For general bodies (GB): $0 < a_\lambda < 1$
- For ideal black bodies (IBB): $a_\lambda = 1$
- It depends on the nature of the surface only

iii) Emissive Power (e):

At a given temperature, the amount of emitted radiations per unit area in per unit time by a body is called as emissive power of the body.

$$GB \Rightarrow e = \frac{Q_{GB}}{At}$$

$$\therefore Q_{GB} = eAt$$

$$IBB \Rightarrow E = \frac{G_{IBB}}{At}$$

$$\therefore G_{IBB} = EAt$$

- Unit: $\frac{\text{Joule}}{m^2\,\text{sec}}$ or $\frac{\text{Watt}}{m^2}$
- dimensions: $[M^1 L^0 T^{-3}]$
- Emissive power of ideal gas body depends on temperature only

  $[E \propto t^4]$, $\therefore [e \propto e_r T^4]$
- But, emissive power of general body depends on temperature and nature of surface.

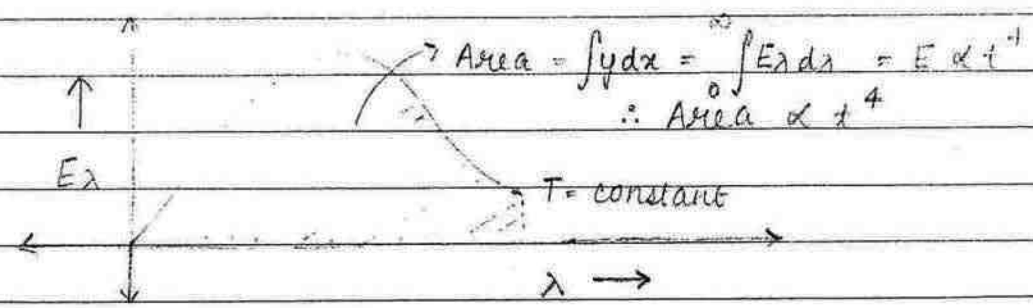
  $a \propto e$ $(a \neq e)$

$a \neq e$, It is because a is a ratio but e is the quantity not a ratio.

iv) Spectral Emission power (e_λ) :
At a given temperature, the amount of emitted radiation per unit area per unit time by a body for λ Å wavelength is called a spectral emissive power.

$$GB \Rightarrow \quad e_\lambda = \frac{(Q_\lambda)_{GB}}{At}$$

$$IBB \Rightarrow \quad E_\lambda = \frac{(Q_\lambda)_{IBB}}{At}$$



$$e_{\lambda 1} + e_{\lambda 2} + e_{\lambda 3} \ldots\ldots\ldots\ldots e_{\lambda\infty}$$

$$= \frac{Q_{\lambda 1}}{At} + \frac{Q_{\lambda 2}}{At} + \frac{Q_{\lambda 3}}{At} \ldots\ldots\ldots\ldots \frac{Q_{\lambda\infty}}{At}$$

$$= \frac{Q_{\lambda 1} + Q_{\lambda 2} + Q_{\lambda 3} \ldots\ldots\ldots Q_{\lambda\infty}}{At} = \frac{Q}{At} = E$$

v) Emissivity / Relative emissivity (e_r) :
At a given temperature, it is the ratio of emissive power of general body to emissive power of ideal black body at identical condition.

$$\boxed{e_r = \frac{e}{E}}$$

$$\therefore e_r = \frac{e \times At}{E \times At} = \frac{Q_{GB}}{Q_{IBB}}$$

- It is unitless
- For GB $\Rightarrow$ $0 < e_r < 1$
- For IBB $\Rightarrow$ $e_r = 1$
- It depends upon the nature of the gas

Ideal Black Bodies :

i) Surface which absorbs all the incident radiation (0 to ∞ Å) at low temperature and emit all these radiations at high temperature.

ii) For IBB, $r = t = 0$, $a = 1$
$a_\lambda = 1$, $e_r = 1$

iii) An ideal black body need not be black in colour, eg: Sun.

iv) Spectrum of an ideal black body is continuous. so, it is called full or white spectrum.

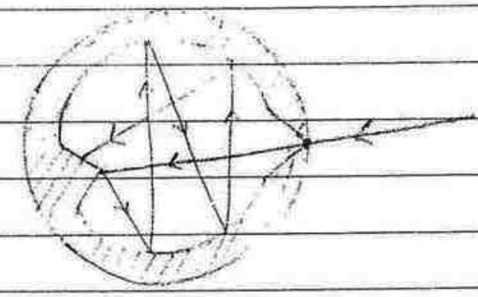
v) Emissive power of ideal black body depends on temperature only but emission power of general body depends on temperature and nature of surface.

vi) In nature, 100% absorption of incident radiation is not possible by any surface.

- The maximum absorptive power is of Platinum Black and carbon black

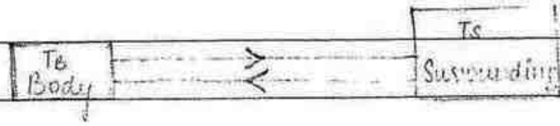
vii) Practically made ideal body:

- Ferry's Ideal Black Body:



- Prevost law of heat exchange:

According to this law emission and absorption of radiation is a continuous process, it means every body emits and absorb radiation to the surrounding at all temperature (except 0 K)



- $T_B > T_s \Rightarrow Q_{emit} > Q_{absorb}$

  $T_B \downarrow$ = cooling effect

  eg: हम और AC कमरा

- $T_B < T_s \Rightarrow Q_{emit} < Q_{absorb}$

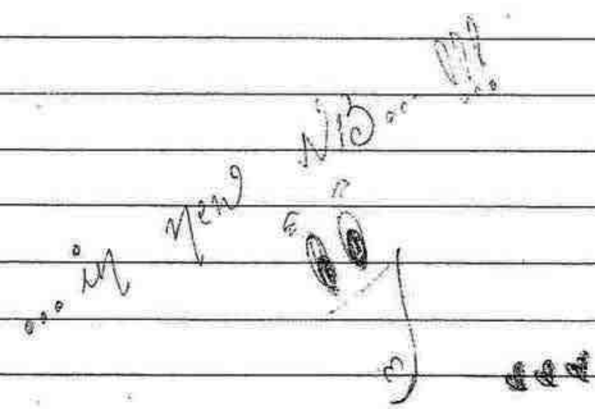
  $T_B \uparrow$ = heating effect

  eg: आप [illegible]

- $T_B = T_s \Rightarrow Q_{emit} = Q_{absorb}$

  T_B = constant , No effect

  eg: आप और हम



... MODE OF HEAT TRANSFER

Kirchoff's law: At a given constant temperature, ratio of spectral emissive power to spectral absorptive power and all bodies will remain constant and is equal to spectral emissive power of Ideal Black Body at same temperature.

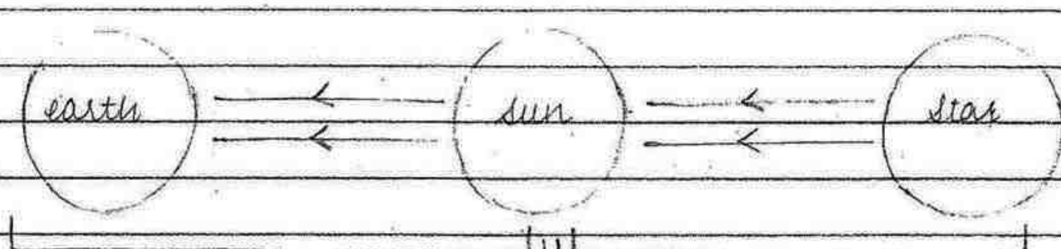
$$\underbrace{\left(\frac{e_\lambda}{a_\lambda}\right)_1 = \left(\frac{e_\lambda}{a_\lambda}\right)_2 = \left(\frac{e_\lambda}{a_\lambda}\right)_3 = \dots\dots\dots}_{G.B} = \underbrace{\left(\frac{E_\lambda}{A_\lambda}\right)}_{IBB} = \text{constant}$$

$\because$ for IBB, $A_\lambda = 1$

$$\therefore \boxed{\underbrace{\left(\frac{e_\lambda}{a_\lambda}\right)}_{G.B} = \underbrace{E_\lambda}_{IBB} = \text{constant}} \quad (\text{at constant temp.})$$

$$\boxed{a_\lambda \propto e_\lambda}$$

$\left(\begin{array}{c}\text{at low}\\ \text{temp}\end{array}\right)$ $\left(\begin{array}{c}\text{at high}\\ \text{temp}\end{array}\right)$ w.r.t. body



high temperature (emit) — low temperature (absorb)

Result:

- Good absorber $\rightleftharpoons$ good emitter
- Bad absorber $\rightleftharpoons$ bad emitter

(at low temp of the body) (at high temp of the body)

Nature of surface (surface finish)

- Dark (black) and rough surface: Good
- Bright (white) and smooth surface: Bad

eg: In desert area, days are hot and nights are cool.
Reason: ∵ sand is rough,
∴ It is good absorber as well as good emitter of heat.

eg: Mudhouses are cooler in summer and warmer in winter.
Reason: ∵ Mud is smooth
∴ It is a bad absorber as well as bad emitter of heat

eg: A black skin person experience more heat in summer and more cold in winter as compared to white skin.
Reason: Black is a good absorber as well as good emitter whereas white is a bad absorber as well as emitter

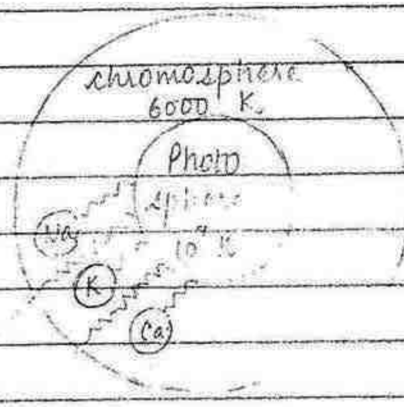
Applications:

Fraun hoffer's line:

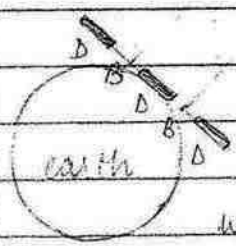
- In normal condition (dark lines): It is due to absorption of chromosphere (which is a good absorber)

- At solar eclipse (Bright light): It is due to emission by chromosphere (which is a good emitter)

* chromosphere is a good absorber as well as good emitter.



Sun



where, D = dark
and B = Bright

Normal condition

Radiation colour: green body appears green because it rejects green colour and absorbs all other colour

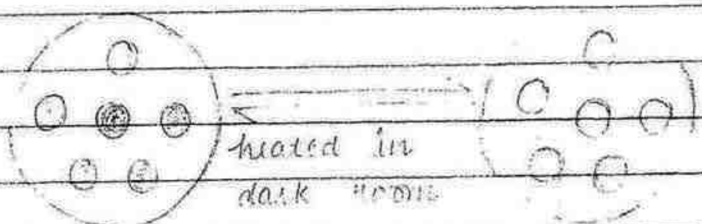
Complementary colours:

Red $\rightleftharpoons$ Green

Blue $\rightleftharpoons$ Yellow

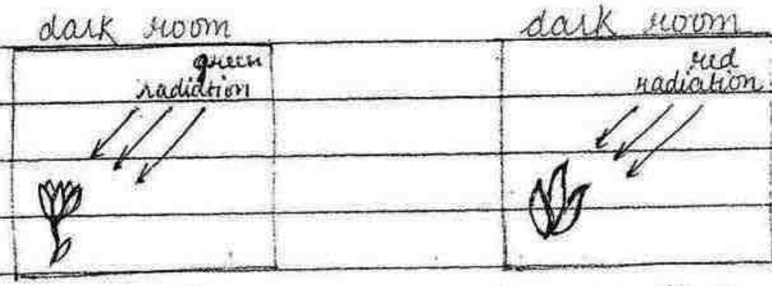
Black $\rightleftharpoons$ white

when a green body is heated in a dark room then it appears red because green is a good absorber of red radiation at low temperature. so it is also a good emitter of red radiation at high temperature.

- 

white ball
Black spot

Black ball
white spot

- 

Appears Black

Appears Black

Stefan's law:
The amount of emitted radiation per unit area per unit time by a black body is directly ~~proprop~~ proportional to fourth power of its absolute temperature

$$E = \frac{Q_{IBB}}{At}$$

$$\therefore E \propto T^4$$

$$\boxed{E = \sigma T^4}$$

where, σ = Stefan's constant

$\sigma = 5.67 \times 10^{-8} \frac{\text{Joule}}{m^2 \sec K^4}$ or $\frac{\text{Watt}}{m^2 \cancel{\sec} K^4}$

dimensions of σ : $[M^1 L^0 T^{-3} K^{-4}]$

Amount of emitted radiation (Q):

$$Q_{IBB} = EAt$$

$$\boxed{Q_{IBB} = \sigma T^4 At} \text{ joule}$$

$$\because e_r = \frac{Q_{GB}}{Q_{IBB}}$$

$$\therefore Q_{GB} = e_r Q_{IBB}$$

$$\therefore \boxed{Q_{GB} = e_r \sigma A T^4 t} \text{ joule}$$

Rate of emitted radiation by IBB : $E_1 = \sigma T^4$

where, T = temperature of body

Rate of absorbed radiation by IBB = rate of emitted radiation by surrounding: $E_2 = \sigma T_0^4$

where, T_0 = temperature of the surroundings

Net rate of loss of radiation by IBB :

$$E = E_1 - E_2$$

$$\therefore \quad E = \sigma\left(T^4 - T_0^{\,4}\right)$$

Net amount of loss of emitted radiation:

$$Q_{IBB} = EAt$$

$$\therefore \boxed{Q_{IBB} = \sigma\left(T^4 - T_0^{\,4}\right) At} \text{ joule}$$

$$e_r = \frac{Q_{GB}}{Q_{IBB}} \qquad \therefore \quad Q_{GB} = e_r \, Q_{IBB}$$

☆☆ $\boxed{Q_{GB} = e_r \sigma A\left(T^4 - T_0^{\,4}\right)t}$ joule

Q.11 Two spheres A and B of same ~~x~~ colour and having radius 4 ~~x~~ cm and 1 cm maintains temperature 127°C and 327°C respectively. The surrounding temperature is 200 K. Calculate ratio of energy radiated by A and B.

$$\because \quad Q = e_r \sigma A\left(T^4 - T_0^{\,4}\right)t$$

$$\therefore \quad Q \propto A\left(T^4 - T_0^{\,4}\right)$$

$$\therefore \quad Q \propto r^2\left(T^4 - T_0^{\,4}\right)$$

$$\frac{Q_1}{Q_2} = \left(\frac{r_1}{r_2}\right)^2 \left[\frac{T_1^{\,4} - T_0^{\,4}}{T_2^{\,4} - T_0^{\,4}}\right]$$

$$\therefore \quad \frac{Q_1}{Q_2} = \frac{16}{1}\left[\frac{400^4 - 200^4}{600^4 - 200^4}\right]$$

$$= \frac{16}{1}\left[\frac{(2^4 \times 200^4) - 200^4}{(3^4 \times 200^4) - 200^4}\right]$$

$$= \frac{16}{1} \times \frac{200^4\,(2^4 - 1)}{200^4\,(3^4 - 1)}$$

$$= \frac{16}{1} \times \frac{16-1}{81-1}$$

$$= 16 \times \frac{15}{80} = \frac{3}{1}$$

$$\therefore \frac{Q_1}{Q_2} = \frac{3}{1}$$

Q.12 If the temperature of ideal black body is increased by 25%, then what will be % of rate of emitted radiation emitted from its surface

$$\because E = \sigma (T^4 - T_0^4)$$

$$\therefore E \propto T^4$$

$$\frac{E_1}{E_2} \propto \frac{T_1^4}{T_2^4}$$

$$\left[\begin{array}{ll} \text{Let } T_1 = 100T & \therefore T_2 = 100T + 25T \\ & \quad = 125T \\ E_1 = 100E & \therefore E_2 = ? \end{array}\right]$$

$$\frac{100E}{E_2} = \left(\frac{100T}{125T}\right)^4$$

$$\frac{100E}{E_2} = \left(\frac{4}{5}\right)^4$$

$$\frac{100E}{E_2} = \frac{256}{625}$$

$$\therefore E_2 = \frac{625 \times 100E}{256}$$

$$= 244E$$

$$\therefore \% \text{ increase} = \frac{E_2 - E_1}{E_1} \times 100 = \frac{\cancel{224E}\ 244E - 100E}{100E} \times 1$$

$$= \frac{144E}{100E} \times 100 = 144\%$$

$$Q_{GB} = e r \sigma A (T^4 - T_0^4) t$$
$$\therefore dQ = e r \sigma A (T^4 - T_0^4) dt$$

- $R_H = \frac{dQ}{dt}$ = Rate of loss of heat.

$$R_H = \frac{dQ}{dt} = e r \sigma A (T^4 - T_0^4) \frac{\text{Joule}}{\text{sec}} = \text{watt}$$

$$\boxed{\therefore R_H = \frac{dQ}{dt} = \frac{e r \sigma A (T^4 - T_0^4)}{J} \frac{\text{cal}}{\text{sec}}}$$

- $R_F = \frac{d\theta}{dt}$ = Rate of fall in temperature

$$dQ = Ms\,d\theta$$
$$\therefore \frac{dQ}{dt} = \frac{Ms\,d\theta}{dt}$$
$$\therefore \boxed{R_H = H_c R_F}$$
$$\left(\because \frac{dQ}{dt} = R_H,\ MS = H_c \text{ and } \frac{d\theta}{dt} = R_F \right)$$
$$\therefore \frac{d\theta}{dt} = \frac{1}{MS} \frac{dQ}{dt}$$

$$\boxed{\therefore R_F = \frac{d\theta}{dt} = \frac{e r \sigma A (T^4 - T_0^4)}{MSJ} \frac{°C}{\text{sec}} \text{ or } \frac{K}{\text{sec}}}$$

- R_H = Rate of loss of heat
  = Rate of emitted radiation per second
  = emitted power $\left(\frac{\text{Joule}}{\text{sec}}\right)$
- R_F = Rate of fall in Temperature
  = Rate of cooling
  = which is cooling faster?

Case I to V : If T, T_0, er = same

$R_H \propto A$ and $R_F \propto \frac{A}{MS}$

<u>Case I</u> : Two solid sphere ($r_1 > r_2$) of different material

- $\because R_H \propto A \propto r^2 \quad (\because A = \pi r^2)$

$\therefore \frac{R_{H1}}{R_{H2}} = \frac{r_1^2}{r_2^2}$

$R_{H1} > R_{H2} \quad (\because r_1 > r_2)$

- $\because R_F \propto \frac{A}{MS} \propto \frac{A}{V\rho S} \quad \left(\because \rho = \frac{M}{V}, \therefore M = \rho V\right)$

$\frac{A}{V\rho S} \propto \frac{r^2}{r^3 \rho S} \quad \left(\because A = \pi r^2 \text{ and } V = 4/3\,\pi\, r^3\right)$

$\therefore R_F \propto \frac{1}{r\rho S}$

$\frac{R_{F1}}{R_{F2}} = \frac{r_2 \rho_2 S_2}{r_1 \rho_1 S_1}$

<u>Case II</u> : ~~To~~ Two solid sphere ($r_1 > r_2$) of same material.

- $\because R_H \propto A \propto r^2 \; (\because A = \pi r^2)$

$\therefore \frac{R_{H1}}{R_{H2}} = \frac{r_1^2}{r_2^2}$

$R_{H1} > R_{H2} \quad (\because r_1 > r_2)$

- $\because R_F \propto \frac{A}{MS} \propto \frac{A}{V\rho S} \quad \left(\because \rho = \frac{M}{V}, \therefore M = \rho V\right)$

$$\frac{A}{V\rho S} \propto \frac{r^2}{r^3 \rho S} \quad \left(\because A = \pi r^2 \text{ and } V = \frac{4}{3}\pi r^3 \right)$$

$$\frac{r^2}{r^3 \rho S} \propto \frac{1}{r \rho S} \quad \left(\rho \text{ and } S = \text{constant} \because \text{same material} \right)$$

$$\therefore R_F \propto \frac{1}{r}$$

$$\frac{R_{F1}}{R_{F2}} = \frac{r_2}{r_1}$$

$\therefore R_{F1} < R_{F2}$ $\quad (\because r_1 > r_2)$

Time taken for cooling

$t_{r_1} > t_{r_2}$ $\quad \left(\because R_F \propto \frac{1}{dt} \right)$

Case III : different solid shaped, cube (l), cylinder ~~(R, t)~~ (r, l) and sphere (r)

- $\because R_H \propto A$ (where A is total surface area)
- cube $= 6l^2$
- cylinder $= \cancel{2\pi R}\ 2\pi r l + 2\pi r^2 = 2\pi r(l+r)$
- sphere $= 4\pi r^2$

- $\because R_F \propto \frac{A}{MS} \propto \frac{A}{V\rho S}$ $\quad \left(\rho, S = \text{constant} \because \text{same material} \right)$

$$\therefore R_F \propto \frac{A}{V}$$

- cube $= \frac{6l^2}{l^3} = \frac{6}{l}$
- cylinder $= \frac{2\pi r l + 2\pi r^2}{\pi r^2 l} = \frac{2\pi r(l+r)}{\pi r^2 l}$
- sphere $= \frac{4\pi r^2}{4/3\ \pi r^3} = \frac{3}{r}$

Case IV : different solid shaped cube (l), cylinder (r, l), sphere (r), disc (r) of same material and same volume

- $\because R_H \propto A$

- $\because R_F \propto \frac{A}{MS} \propto \frac{A}{V\rho S}$ $\left(\begin{array}{l} \rho, S, V = \text{constant} \\ \because \text{same material and volume} \end{array} \right)$

  $\therefore R_F \propto \frac{A}{V}$

Maximum surface area is of disc because maximum mass is on the surface so R_H, R_F is maximum for disc.

~~Maximum~~ Minimum surface area is of sphere because maximum mass is inside the sphere, so R_H, R_F is minimum for sphere.

Case V : A solid and a hollow sphere of same material and same radius.

- $\because R_H \propto A \propto r^2$

  $\therefore R_{H_1} = R_{H_2}$ $(\because r_1 = r_2)$

- $\because R_F \propto \frac{A}{MS} \propto \frac{r^2}{MS}$ $\left(\begin{array}{l} \text{same material and} \\ \text{same radius} \end{array} \right)$

  $R_F \propto \frac{1}{M}$

$$\boxed{\begin{array}{l} \therefore M_{solid} > M_{hollow} \\ \quad R_{F\,solid} < R_{F\,hollow} \\ \text{Time taken for cooling, } T_{solid} > T_{hollow} \end{array}}$$

Q.13 Case VI : A sphere at temperature 900 K is placed in an environment of Temperature 300 K. It's cooling rate is 8°C/min. If its temperature is reduced to 600 K, then its cooling rate in same surrounding will be.

$$\because R_F = \frac{e\sigma A}{MSJ}(T^4 - T_0^4)$$

$$\therefore \frac{R_{F1}}{R_{F2}} = \frac{(T_1^4 - T_0^4)}{(T_2^4 - T_0^4)}$$

$$\frac{8}{R_{F2}} = \frac{900^4 - 300^4}{600^4 - 300^4}$$

$$\therefore \frac{8}{R_{F2}} = \frac{3^4 \times 300^4 - 300^4}{2^4 \times 300^4 - 300^4}$$

$$\frac{8}{R_{F2}} = \frac{300^4}{300^4}\left(\frac{3^4 - 1}{2^4 - 1}\right)$$

$$\therefore \frac{8}{R_{F2}} = \frac{80}{15}$$

$$R_{F2} = \frac{15 \times 8}{80} = \frac{3}{2}$$

$$\therefore R_{F2} = 1.5\ °C/min$$

Newton's law of cooling :
According to this law, the rate of cooling of a body is directly proportional to temperature difference between body and surrounding.

$$R_F = \frac{d\theta}{dt} \propto (\theta - \theta_0)$$

$$\boxed{\therefore \frac{d\theta}{dt} = -K(\theta - \theta_0)}$$ -ve indicates decrease in rate of cooling with time

K = cooling constant

$$K = \frac{4e r \sigma A \theta_0^3}{MSJ}$$

where, θ = temperature of body
θ_0 = surrounding temperature
$\theta - \theta_0$ = excess temperature

condition : $\theta - \theta_0 < 35^\circ c$

eg: $\underset{(100^\circ C)}{A} \xrightarrow{\text{cold milk}} 90^\circ C \xrightarrow[E \propto T^4]{5 \text{ min}} 80^\circ C$

$\underset{(100^\circ C)}{B} \xrightarrow[E \propto T^4]{5 \text{ min}} 88^\circ C \xrightarrow{\text{cold milk}} 78^\circ C$

(Hence more loss of heat at high temperature)

graph between θ (temperature of body) and t (time):

$$\frac{d\theta}{dt} = -K(\theta - \theta_0)$$

$$\int \frac{1}{\theta - \theta_0} d\theta = -K \int dt$$

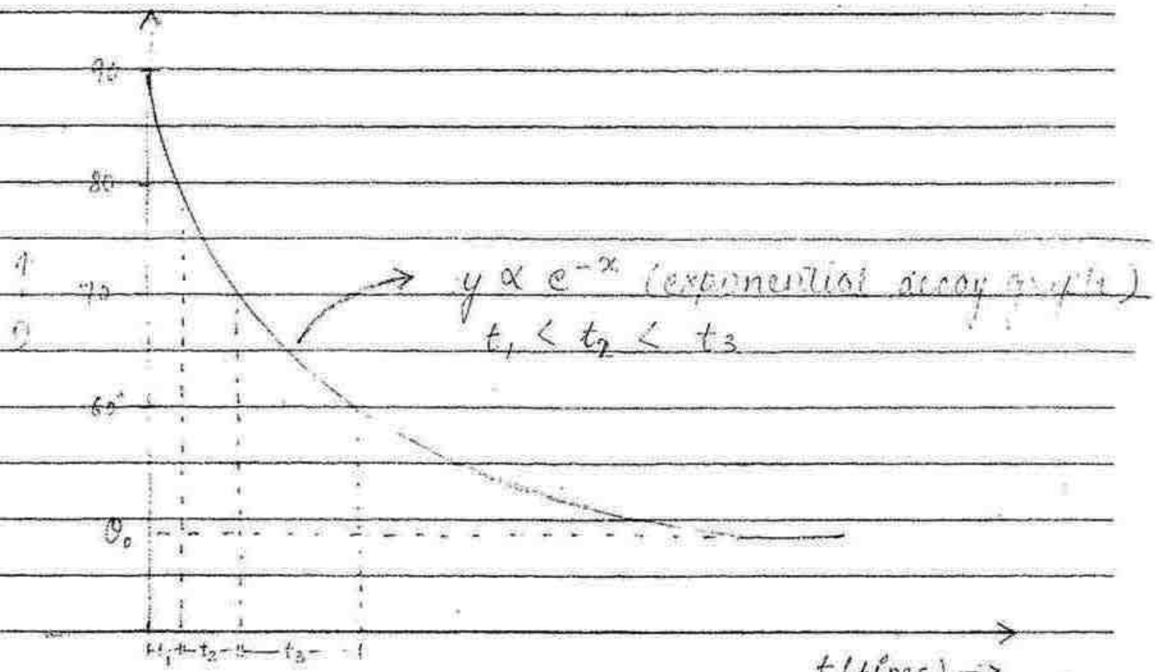
$$\log_e(\theta - \theta_0) = -Kt + c$$

$$e^{-Kt+c} = \theta - \theta_0$$

$$\theta = e^{-Kt+c} + \theta_0$$

$$y = e^{-x} + c$$

$$\left[\begin{array}{ll} \log_{10} 100 = 2 & \therefore 10^2 = 100 \\ \log_x y = z & \therefore x^z = y \end{array}\right]$$



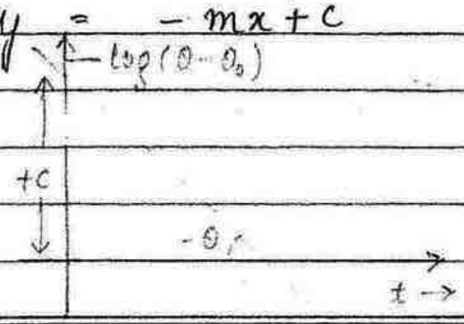
Graph between $\log_e(\theta-\theta_0)$ and time (t):

$$\frac{d\theta}{dt} = -K(\theta-\theta_0)$$

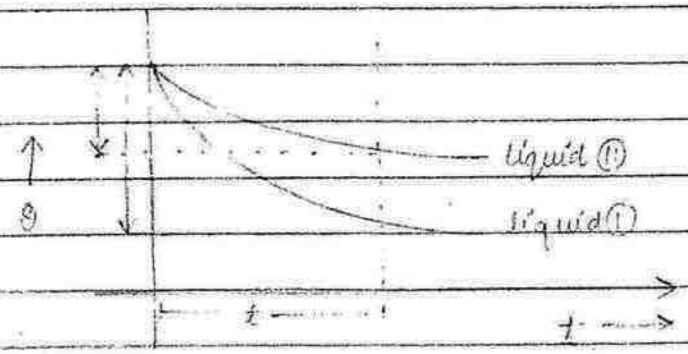
$$\int \frac{1\,d\theta}{\theta-\theta_0} = -K\int dt$$

$$\log_e(\theta-\theta_0) = -Kt + c$$

$$y = -mx + c$$



Q.14 Find out the slope of rate of fall in temp



$\therefore R_F = \frac{d\theta}{dt} = \text{slope}$

$\therefore \text{slope} \propto d\theta$

$(\text{slope})_{liq\ I} > (\text{slope})_{liq\ II}$

$R_{F1} > R_{F2}$

OR

$R_F \propto d\theta \quad (dt = \text{same})$

Rate of fall in temperature:

$\theta_1 \xrightarrow[t]{\text{temperature fall to}} \theta_2$

$$\frac{d\theta}{dt} = -K(\theta - \theta_0)$$

$$\frac{\theta_2 - \theta_1}{t} = -K\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$$

$$\left(\because \theta_{mid} = \frac{\theta_1 + \theta_2}{2} = \text{radiation correction}\right)$$

$$\frac{-(\theta_1 - \theta_2)}{t} = -K\left(\frac{\theta_1 + \theta_2}{2} - \theta_0\right)$$

☆☆☆ $$\boxed{\therefore \frac{\theta_1 - \theta_2}{t} = K\left[\frac{\theta_1 - \theta_2}{2} - \theta_0\right]}$$

Q. 15 $60^\circ C \longrightarrow 40^\circ C$ (time = 5 min)

$40^\circ C \longrightarrow 30^\circ C$ (time = ?)

given $\theta_0 = 20^\circ C$

$$\because \frac{\theta_1 - \theta_2}{t} = K\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$$

$$\therefore \frac{60-40}{5} = K\left[\frac{60+40}{2} - 20\right]$$

$$4 = K(50-20)$$

$$\therefore K = \frac{4}{50-20}$$

$$K = \frac{4}{30} = \frac{2}{15}$$

$$\therefore \frac{40-30}{t} = K\left[\frac{40+30}{2} - 20\right]$$

$$= \frac{10}{t} = \frac{2}{15}\left(35-20\right) \qquad \left[\because K = \frac{2}{15}\right]$$

$$= \frac{10}{t} = \frac{2}{15} \times 15$$

$$\therefore t = \frac{10}{2} = 5 \text{ min}$$

Q.16 $70^\circ C \longrightarrow 60^\circ C$ ($t_1 = 5$ min)

$60^\circ C \longrightarrow 50^\circ C$ ($t_2 = 8$ min)

$50^\circ C \longrightarrow 40^\circ C$ (Find t_3 and θ_0)

$$\because \frac{\theta_1 - \theta_2}{t_1} = K\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$$

$$\therefore \frac{70-60}{5} = K\left[\frac{70+60}{2} - \theta_0\right] \quad \text{— (I)} \quad \text{and}$$

$$\frac{60-50}{8} = K\left[\frac{60+50}{2} - \theta_0\right] \quad \text{— (II)}$$

dividing (ii) by (i),

$$\frac{\frac{10}{5} = K\left(65 - \theta_0\right)}{\frac{10}{8} = K\left(55 - \theta_0\right)}$$

$$\Rightarrow \frac{8}{5} = \frac{65-\theta_0}{55-\theta_0}$$

$$= 440 - 8\theta_0 = 325 - 5\theta_0$$

$$= 440 - 325 = 8\theta_0 - 5\theta_0$$

$$= 115 = 3\theta_0$$

$$\therefore \theta_0 = 38.33$$

Now, putting θ_0 in (i), we get

$$\frac{10}{5} = K\,(65 - 38.33)$$

$$\therefore K = \frac{2}{26.67} = \frac{1}{13.33}$$

$$\therefore \frac{50-40}{t_3} = \frac{1}{13.33}\left[\frac{50+40}{2} - 38.33\right]$$

$$\frac{10}{t_3} = \frac{1}{13.33}\left[45 - 38.33\right]$$

$$\frac{10}{t_3} = \frac{1}{13.33} \times 6.67$$

$$\therefore \cancel{t_3} \frac{10}{t_3} = \frac{1}{\cancel{0.5}\,2}$$

$$\therefore t_3 = 10 \times \cancel{0.5}\ 2$$

$$= 20 \text{ min}$$

Q.17 If initial temperature of the body is 40°C, room temperature is 20°C. After 5 minutes excess temperature is reduced to its half value, then calculate temp of the body after next 3 minutes.

$$\theta_1 \xrightarrow{5\ min} \theta_2 \xrightarrow{3\ min} \theta_3$$
$40^\circ C$

$$\therefore \theta_1 - \theta_0 = 40 - 20 = 20^\circ C$$

$$\theta_2 - \theta_0 = \frac{1}{2} \times 20 = 10^\circ C$$

$$\therefore \theta_2 = 10 + \theta_0 = 10 + 20 = 30^\circ C$$

$$\because \frac{\theta_1 - \theta_2}{t} = K\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$$

$$\frac{40 - 30}{5} = K\left[\frac{40 + 30}{2} - 20\right]$$

$$\frac{10}{5} = K\left[35 - 20\right]$$

$$2 = K \times 15$$

$$\therefore K = \frac{2}{15}$$

$$\because \frac{\theta_2 - \theta_3}{t} = K\left[\frac{\theta_2 + \theta_3}{2} - \theta_0\right]$$

$$\frac{30 - \theta_3}{3} = \frac{2}{15}\left[\frac{30 + \theta_3}{2} - 20\right]$$

$$30 - \theta_3 = \frac{2}{5}\left[\frac{30 + \theta_3 - 40}{2}\right]$$

$$\therefore 5(30 - \theta_3) = \theta_3 - 10$$

$$150 - 5\theta_3 = \theta_3 - 10$$

$$150 + 10 = 6\theta_3 \cancel{+\theta_3}.$$

$$160 = 6\theta_3.$$

$$\therefore \theta_3 = \frac{160}{6}$$

$$= 26.66^\circ C$$

Limitations :

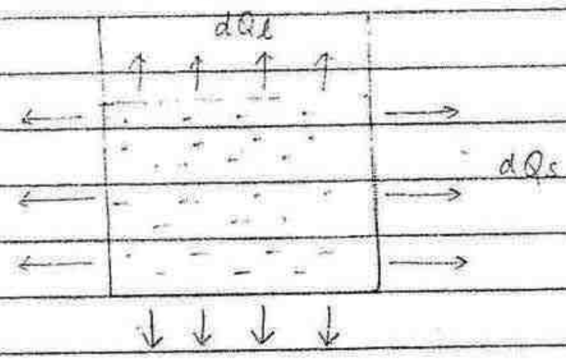
i) Newton's laws of cooling (NLC) can be used only when temperature difference is small $(\theta - \theta_0) < 35°c$ but Stefen's law can be used for all temperature difference.

ii) NLC can be determined by Stefen's law

iii) NLC can be used only to calculate specific heat of liquid.

To calculate specific heat of a liquid :

- Step 1 : Rate of loss of heat by one liquid.



$\theta_1 \xrightarrow{\text{temp fall to } t} \theta_2$

$$\therefore \frac{dQ}{dt} = \frac{dQ_l + dQ_s}{dt}$$

$$\frac{dQ}{dt} = \frac{M_l S_l (\theta_1 - \theta_2) + M_s S_s (\theta_1 - \theta_2)}{t}$$

$$\frac{dQ}{dt} = \frac{(M_l S_l + M_s S_s)(\theta_1 - \theta_2)}{t}$$

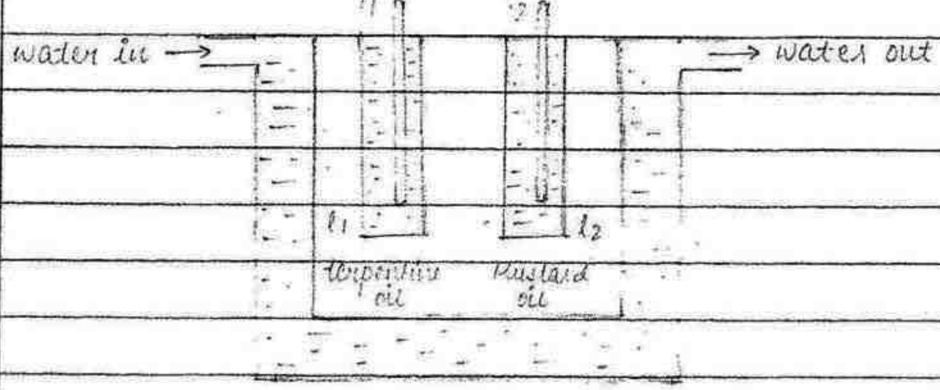
- Step 2: Water equivalent of calorie meter (w):
Water equivalent of any substance is quantity of water in gram whose heat capacity is equal to heat capacity of the substance

$$\therefore \ (H_c)_{substance} = (H_c)_{water}$$
$$M_s S_s = M_w S_w$$
$$M_s S_s = M_w \times 1 \quad [\because S_{water} = 1\ cal/g^\circ C]$$
$$\therefore \ M_s S_s = w \times 1 \quad (\text{where } w \text{ is in gm})$$

$$\boxed{\therefore \ \frac{dQ}{dt} = \frac{(M_l S_l + w)(\theta_1 - \theta_2)}{t}} \quad \text{in CGS}$$

- Step 3: Compare two liquids:
Two liquids are cooled at identical condition (initial temperature, surrounding Temperature, surface area, nature of ~~gas,~~ surface, and volume are same) then, rate of loss of heat by both liquid is same

$$\theta_1 \xrightarrow{\text{temp. fall to } t} \theta_2$$



$$R_H = \frac{dQ}{dt} = \frac{e_r \sigma A \left(T_1^4 - T_0^4\right)}{J}$$

$$\therefore R_F = \frac{d\theta}{dt} \propto \frac{1}{MS}$$

$$\left(\frac{dQ}{dt}\right)_{liquid\ I} = \left(\frac{dQ}{dt}\right)_{liquid\ II}$$

$$\frac{M_1S_1 + w_1\ (\theta_1 - \theta_2)}{t_1} = \frac{M_2S_2 + w_2\ (\theta_1 - \theta_2)}{t_2}$$

$$\therefore \boxed{\frac{M_1S_1 + w_1}{t_1} = \frac{M_2S_2 + w_2}{t_2}} \quad \text{in CGS}$$

$$\boxed{\frac{V\rho_1S_1 + w_1}{t_1} = \frac{V\rho_2S_2 + w_2}{t_2}} \quad \text{in CGS}$$

$$\left(\because \rho = \frac{M}{V}, \ \therefore M = \rho V\right)$$

$$dQ_l >>>> dQ_s$$

$$M_lS_l >>>> M_sS_s$$

$$\boxed{\frac{M_1S_1}{t_1} = \frac{M_2S_2}{t_2}} \quad \text{(when } w \text{ is not given)}$$

$$\boxed{\frac{\rho_1S_1}{t_1} = \frac{\rho_2S_2}{t_2}}$$

Solar constant (S):

The amount of received radiation per unit area per unit time on the earth from the sun is called as solar constant

- The amount of emitted radiation per unit area per unit time from the sun = E

- The amount of emitted radiation by $4\pi R^2$ area in per unit time from the sun = $E \times 4\pi R^2$

- The amount of received radiation by $4\pi R^2$ area in per unit time on the orbit sphere = $E \times 4\pi R^2$

- The amount of received radiation per unit area per unit time on the orbit sphere. (on the earth), $S = \frac{E \times 4\pi R^2}{4\pi d^2}$

$$\therefore S = \frac{ER^2}{d^2}$$

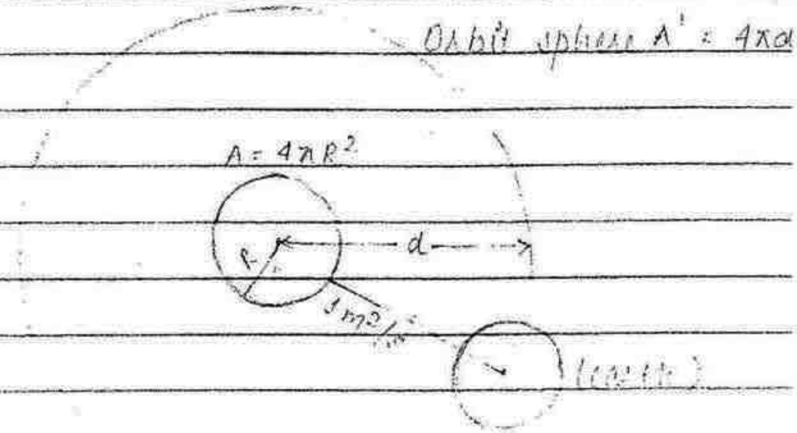
★ $\boxed{S = \sigma T^4 \times \frac{R^2}{d^2}}$

$S \propto \frac{1}{d^2}$ $\quad \therefore \sqrt{S} \propto \frac{1}{d}$

$S_{earth} = 1340 \frac{watt}{m^2} \simeq 1400 \frac{watt}{m^2}$

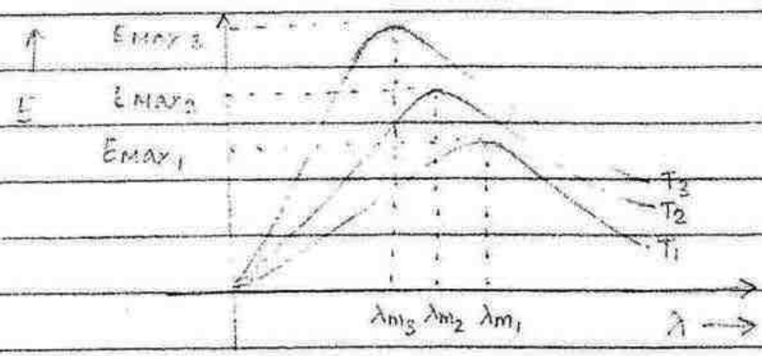
$= 1.4 \text{ K watt}/m^2$

$S_{earth} = 1.94 \frac{cal}{cm^2 \, mn} \simeq 2 \frac{cal}{cm^2 \, mn}$



Solar constant (S) is measured by : Pyroheliometer

Spectral energy distribution curve :



$T_1 < T_2 < T_3$

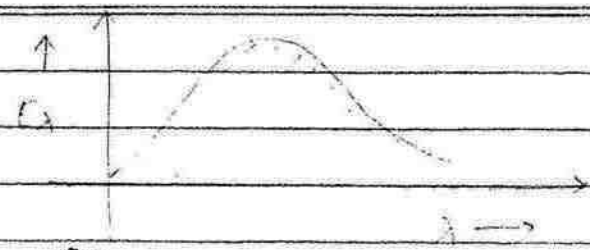
$(Area)_I < (Area)_{II} < (Area)_{III}$ $[\propto T^4]$

$E_1 < E_2 < E_3$ $[\propto T^4]$

$E_{max_1} < E_{max_2} < E_{max_3}$ $[\propto T^5]$

$\lambda_{m_1} > \lambda_{m_2} > \lambda_{m_3}$ $\left[\propto \frac{1}{T}\right]$

$\nu_{m_1} < \nu_{m_2} < \nu_{m_3}$ $[\propto T]$



$$Area = \int_0^\infty E_\lambda d\lambda = E$$

$$\therefore E \propto T^4$$

$$Area \propto T^4$$

Results:

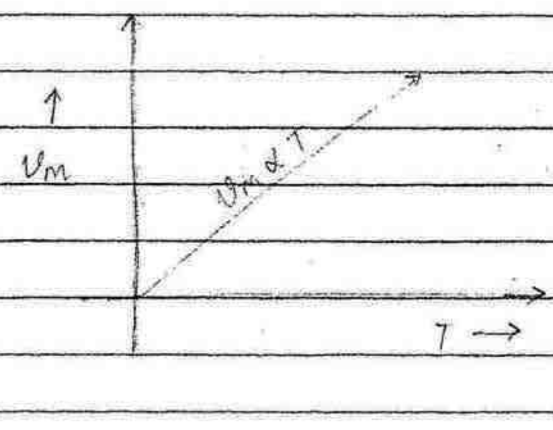
i) $Area \propto E \propto t^4$

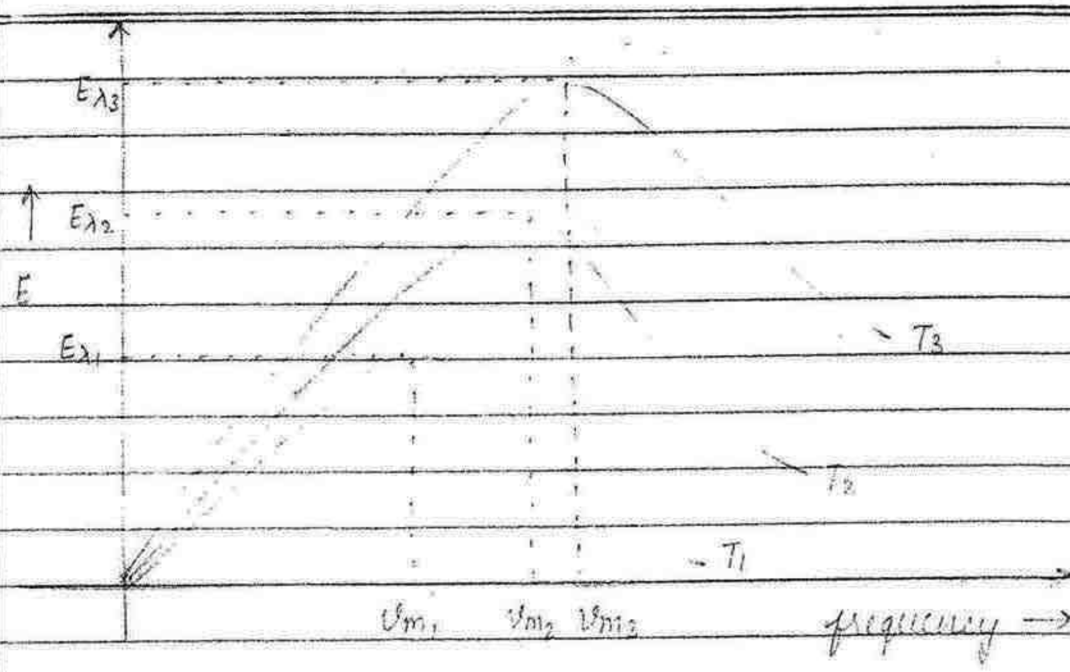
$$\therefore \frac{Area\ I}{Area.\ II} = \left(\frac{T_1}{T_2}\right)^4$$

ii) $E_{max} \propto T^5$

iii) $\lambda_m \propto \frac{1}{T}$ $\quad\therefore \frac{\lambda_{m1}}{\lambda_{m2}} = \frac{T_2}{T_1}$

iv) $\nu_m \propto \frac{1}{\lambda_m} \propto T$ $\quad\therefore \nu_m \propto T$





Special Points :

i) At a given temperature, as the wavelength increases, the amount of emitted radiation becomes maximum and then decreases.

ii) Emission spectrum of Black Bodies is continuous but amount of emitted radiation is different for different wavelength

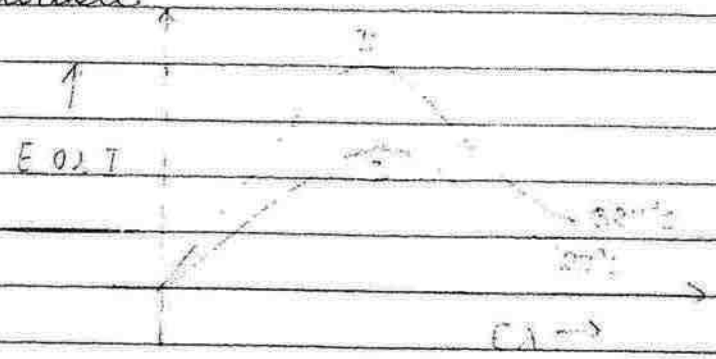
iii) At a constant temperature, area enclosed between curve and wavelength axis represent total amount of emitted radiation (E,

iv) Wein's 5th power law:
Maximum amount of emitted radiation from an ideal black body is proportional to 5th power of absolute temperature of IBB.

$\therefore E_{Max} \propto T^5$

* If the temperature of black body becomes double then total amount of emitted radiation is 16 times but maximum amount of emitted radiation becomes 32 times

Q.18 Calculate the ratio of area, when temperature becomes double.



$\because$ Area $\propto T^4$

$$\therefore \frac{\text{Area}_{I}}{\text{Area}_{II}} = \left(\frac{T_1}{T_2}\right)^4$$

$$= \left(\frac{300}{600}\right)^4$$

$$\therefore \frac{\text{Area}_{I}}{\text{Area}_{II}} = \frac{1}{16}$$

v) Wein's displacement law:
On increasing the temperature of ideal black body, the wavelength corresponding to maximum emission decreases

$$\therefore \lambda_m \propto \frac{1}{T}$$

$$\lambda_m = \frac{b}{T}$$

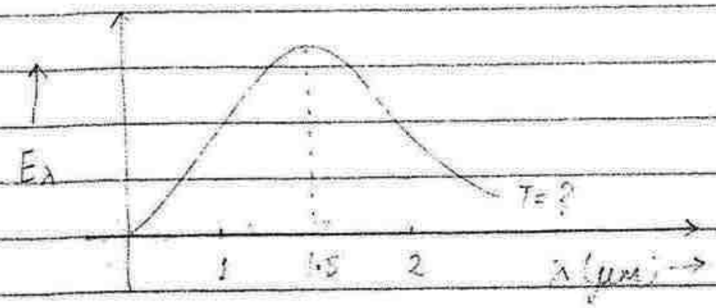
where, $b =$ wein's constant

$b = 2.93 \times 10^{-3}$ m K

dimensions of $b = [M^0 L^1 T^0 K^1]$

$\therefore \boxed{\lambda m_1 T_1 = \lambda m_2 T_2}$ (T in kelvin)

Q.19 Calculate temperature corresponding to given wavelength (μm)



$\because T = \dfrac{b}{\lambda m}$

$= \dfrac{2.93 \times 10^{-3} \text{ m K}}{1.5 \times 10^{-6} \text{ m}}$ $[\because 1 \mu m = 10^{-6} m]$

$= 2 \times 10^{6-3}$ K

$= 2 \times 10^3$ K

$= 2000$ K

graph between log λm and log T

$\lambda m = \dfrac{b}{T}$ $\left(\because T = \dfrac{b}{\lambda m}\right)$

$\therefore \log \lambda m = \log \left(\dfrac{b}{T}\right)$

$\log \lambda m = \log b - \log T$

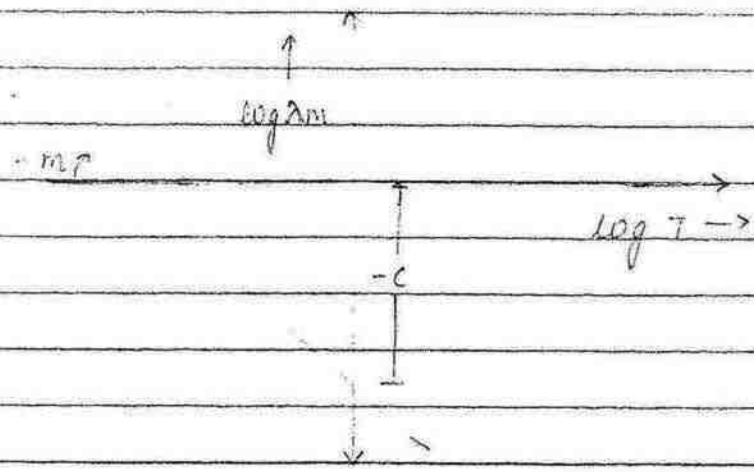
$\therefore \log \lambda_m = -\log T + \log b$

* $y = -mx \; - \; c$, [illegible]

$$\left[\begin{array}{l} \because \log b = \log (2.93 \times 10^{-3}) \\ \quad \log 2.93 + \log 10^{-3} \\ \quad \log 2.93 - 3 \log 10 \\ \quad 0.47 - 3 \times 1 \\ \quad \log b = -2.53 \end{array}\right]$$

* Hence, the value of log becomes negative when the power ~~of~~ is negative.

$$\left[\begin{array}{l} \log xy = \log x + \log y \\ \log \left(\frac{x}{y}\right) = \log x - \log y \end{array}\right.$$



Graph between $\log E$ and $\log T$

$E = \sigma T^4$

$\log E = \log (\sigma T)^4$

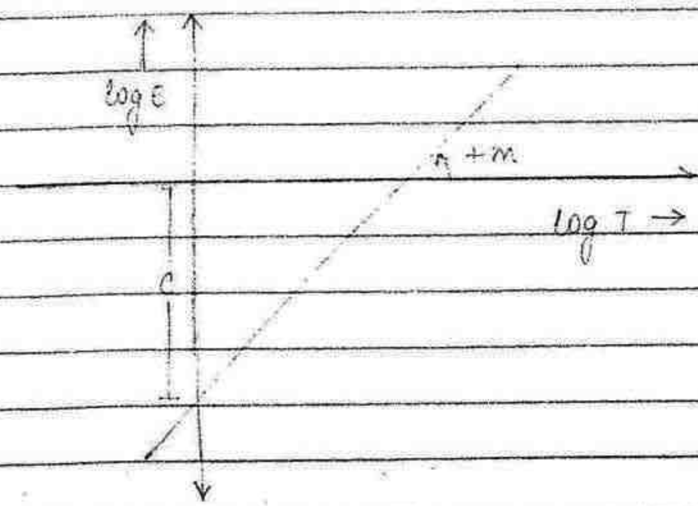
$$= \log \sigma + \log T^4$$
$$\log \sigma + 4 \log T$$
$$\therefore \log E = 4 \log T + \log \sigma$$

☆ $$y = mx - c$$ → memory tips

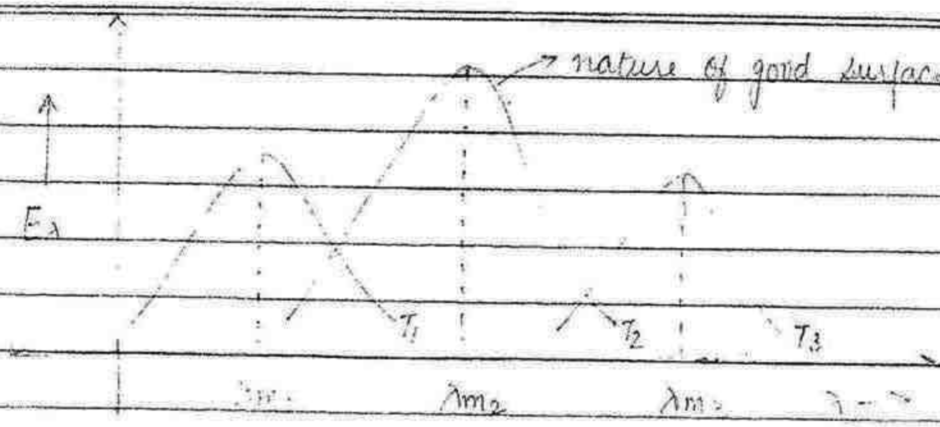
$$\boxed{\begin{aligned} \because \log \sigma &= \log (5.67 \times 10^{-8}) \\ &\log 5.67 + \log 10^{-8} \\ &\log 5.67 - 8 \log 10 \\ &0.7 - 8 \times 1 \\ \log \sigma &= -7.3 \end{aligned}}$$

and

$$\left[\begin{aligned} \log xy &= \log x + \log y \\ \log \left(\frac{x}{y}\right) &= \log x - \log y \end{aligned} \right]$$



Q.20. Calculate the Order of λm and T from the following graph.



* curve of the same body can never intersects each other.

$\therefore \lambda m_1 < \lambda m_2 < \lambda m_3$

$\therefore T_1 > T_2 > T_3 \quad \left[\because \lambda m \propto \frac{1}{T} \right]$