Thermal Properties of Matter

MODE OF HEAT TRANSFER

Heat is a form of energy which transfers from a body at higher temperature to a body at lower temperature. The transfer of heat from one body to another may take place by any one of the following modes.

(1) Conduction (2) Convection (3) Radiation

Conduction :- The process in which the material takes an active part by molecular action and energy is passed from one particle to another is called conduction. It is predominant in solids.

Convection :- The transfer of energy by actual motion of particle of medium from one place to another is called convection. It is predominant is fluids (liquids & gases).

Radiation :- Quickest way of transmission of heat is known as radiation. In this mode of energy transmission, heat is transferred from one place to another without effecting the inter-venning medium.

Conductions	Convections	Radiation
Heat Transfer due to temperature difference.	Heat due to density difference.	Heat transfer without any medium
Due to free electron or vibration motion of molecules	Actual motion of particle	Rays form
Heat transfer in solid body (Hg)	Heat transfer in fluids (Liquid + gas)	All
Slow process	Slow process	Fast process (3×10^8 m/sec.)
Irregular path	Irregular path	Straight line (like light radiation) It make also shadow

THERMAL RADIATION

The process of the transfer of heat from one place to another place without heating the intervening medium is called radiation.

Section – A
Special points about Radiation

(1) Hot body emit energy is called as thermal radiations.

(2) Medium is not require for the propogation of thermal radiation and can travale in vacuum.

(3) Radiation which posses through any medium, raditions must be slightly absorbed by medium according to its absorptive power so temperature of medium slightly increases.

(4) Heat radiation are always obtained in **infra–red** region of **electromagnetic** wave spectrum so they are called **Infra red rays**.

(5) The wavelength range of thermal radiation is greater that light radiation (7800 Å to 4×10^6 Å)

(6) Radiation travels in straight line and speed equal to light radiation.

(7) In order to obtain a spectrum of radiation, a special prism used like **KCI prism, Rock salt prism Flourspar prism.** Normal glass prism or Quartz prism can not be used (because it absorbed some radiation).

(8) Radiation intensity measured with a specific device named as **Bolometer.**

(9) Thermal radiations is incident on a surface, it exerts pressure on the surface, which is known as **Radiation Pressure**.

(10) Radiation shows all optical properties and radiation intensity from a point source obey's inverse square law [$I \propto 1/(d)^2$]

Device for measuring thermal Radiation :-

⇒ Bolometer

⇒ Differential air thermometer

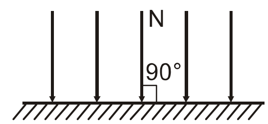
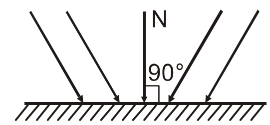
⇒ Thermopile

⇒ Crook's radiometer

⇒ Boyle's radio micro meter

Pyrometer => It's measure only high temperature.

Types of thermal Radiation :- Two types of thermal radiation.

Plane Radiation	Diffuse Radiation
 Radiations which are incident on a surface normally **Pressure on the surface (P)** P = 2u (Perfect reflecting surface) P = u (Perfectly absorbing surface where u = Energy density = E/V	 Incident on the surface at all angles (except $\pi/2$) **Pressure on the surface (P)** P = 2u/3 (For perfect reflecting surface) P = u/3 (For perfect absorbing surface)

Spectrum of electro magnetic wave's (By Mexwell's Concept)

1. Maxwell on the basic of his electromagnetic theory proved that all radiations are electromagnetic waves and their sources are vibrations of charged particles in atoms and molecules.

2. The wavelength corresponding to maximum emission of radiations shifts from longer wavelength to shorter wavelength as the temperature increases. Due to this the colour of a body appears to be changing.

Cosmic Rays	γ–Ray	X–Ray	U.V. Rays	Visible Light VIBGYOR	Infra-red thermal	Micro waves	Radio & T.V. waves

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

* Wavelength range of Radiations : 0 to ∞
* Wavelength of heat radiations : 7800 Å to 4×10^6Å
* Width of visible region : 4000 Å
* VIBG.YOR $\leftarrow$ T, $\lambda \rightarrow$

$\downarrow$

White = 1600 °C

* $\dfrac{\lambda_{Red}}{\lambda_{Voilet}} = \dfrac{7800}{4000} \approx 2$

Basic Fundamental definition :-

(i) Energy Density (u) : J/m^3

The radiation energy of whole wavelength present in unit volume at any point in space is defined as energy density.

(ii) Spectral energy density (u_λ) : J/m^3 Å

$$\boxed{u = \int_0^\infty u_\lambda d\lambda} \qquad J/m^3$$

(iii) Absorptive power or absorptive coefficient (a): Unit Less

The ratio of amount of radiation absorbed by a surface (Q_a) to the amount of radiation incident (Q) upon it is defined as the coefficient of absorption. i.e. ($a = Q_a/Q$)

(iv) Spectral absorptive power (a_λ) :

$a_\lambda = \dfrac{Qa_\lambda}{Q}$ Also called monochromatic absorptive coeffecient.

At a given wavelength $\boxed{a = \int_0^\infty a_\lambda d\lambda}$ For IBB a_λ and $a = 1$, unit of a_λ = unitless

(v) Emmisive power (e) :– J/m^2 sec.

The amount of heat radiation emitted by unit area of the surface in one second at a particular temperature.

(vi) Spectral Emmisive power (e_λ) :- J/m^2 sec Å

The amount of heat radiation emitted by unit area of the body in one second in unit spectral region at a given wavelength.

Emissive power or total emissive power

$$\boxed{e = \int_0^\infty e_\lambda \; d\lambda}$$

(vii) Emissivity (e)/ Relative emissivity (e_r) : (Imp.)

$$e_r = \frac{Q_{GB}}{Q_{IBB}} = \frac{e_{GB}}{E_{IBB}}$$

$$= \frac{\text{Emitted radiation by gray body}}{\text{Emitted radiation by ideal black body}}$$

[where GB = Gray body or general body, IBB = Ideal Black body]

(i) No unit (iii) For IBB $e_r = 1$

(iv) range $0 < e_r < 1$

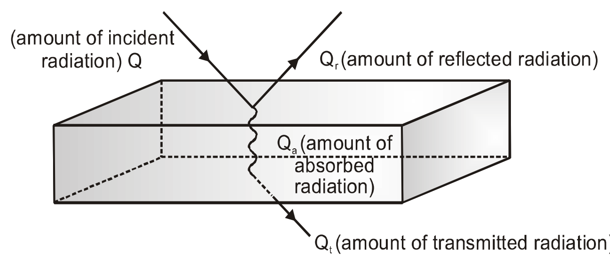
Spectral, Absorptive & Transmittive power of a given body surface

Due to incident radiations on the surface of a body following phenomena occur by which the radiation is divided into three parts.

(a) Reflection

(b) Absorption

(c) Transmission



From energy conservation –

$Q = Q_r + Q_a + Q_t \Rightarrow \dfrac{Q_r}{Q} + \dfrac{Q_a}{Q} + \dfrac{Q_t}{Q} = 1$

$r + a + t = 1$

Reflective Coefficient\Reflection power (r) = Q_r/Q,

Absorptive Coefficient\Absorption power (a) = Q_a/Q,

Transmittive Coefficient\Transmisstion power (t) = Q_t/Q

r = 1 and a = O , t = O $\Rightarrow$ Perfect reflector

a = 1 and r = O, t = O $\Rightarrow$ ideal absorber (Ideal Black Body)

t = 1 and a = O, r = O $\Rightarrow$ perfect transmitter (Diathermanous)

Solved Examples

Ex.1 Total radiations incident on body = 400 J, 2 0 % radiation reflected and 120 J absorbs

Then find out % of transmittive power

Sol. $Q = Q_t + Q_r + Q_a \Rightarrow 400 = 80 + 120 + Q_t$

$\Rightarrow Q_t = 200 \quad \Rightarrow$ is 50% Ans

Ex.2 25% absorb, 25 Cal passes out transmits and total incident radiation Q = 500 J

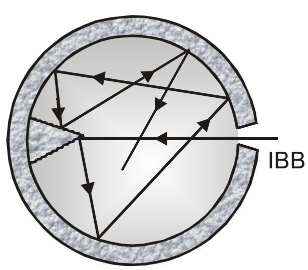
Then find out % of reflective power

Sol. $500 = 105 + 125 + Q_r \quad \Rightarrow Q_r = 500 - 250$

reflective power $\Rightarrow \frac{250}{500} \times 100 \Rightarrow$ 50% Ans.

Ideal Black Body (IBB) :

* For a body surface which **absorbs** all incident thermal radiatiions at **low temperature** irrespective of their wave length and **emitted out** all these absorbed radiations at **high temperature** assumed to be an ideal black body surface.
* The identical parameters of an ideal black body is given by



Ferry's IBB

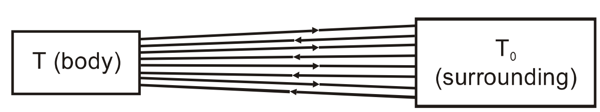
$a = a_\lambda = 1$ and $r = 0 = t$, $e_r = 1$

* The nature of emitted radiations from ideal black body surface only depends on its **temperature**
* The radiations emitted from ideal black body surface called as either **full** or **white radiations.**
* At any temperature the spectral energy distribution curve for an IBB surface is always **continous** and according to this concept if the spectrum of a heat source obtained to be **continous** then it must be placed in group of IBB like kerosene lamp; oil lamp Heating filament etc.
* There are two experimentally ideal black body (a) Ferry's IBB (b) Wien's IBB.
* At **low temperature** IBB surface is a **perfect absorber** and at a **high temperature** it proves to be a **good emitter**.
* An Ideal Black Body need not be black colour (eg. sun)

Prevost's theory of heat energy exchange :– (Except 0 Kelvin)

* **According to Prevost at every possible temperature there is a continuous heat energy exchange between a body and its surrounding and this exchange carry on for infinite time.**
* The relation between temperature difference of body with its surrounding decides whether the body experience **cooling effect** or **heating effect** in the given investment.
* ***When a cold body is placed in the hot surrounding***, the body radiates less energy and absorbs more energy from the surrounding, therefore the temperature of body **increases**.
* ***When a hot body placed in cooler surrounding***. The body radiates more energy and absorb less energy from the surroundings. Therefore temperature of body **decreases**.

– ***When the temperature of a body is equal to the temperature of the surrounding***. The energy radiated per unit Time by the body is equal to the energy absorbed per unit time by the body, therefore its temperature remains **constant**.



KEY POINTS

1. At absolute Zero temperature (0 kelvin) all atoms of a given substance remains in ground state, so, at this temperature emission of radiation from any substance is impossible, so prevost's heat energy exchange theory does not applied at this temperature, so it is called **limited temperature** of prevosts theory.

2. With the help of prevost's theory rate of cooling of any body w.r.t. its surroundings can be worked out (applied to Stefen Boltzman law, Newton's law of cooling.)

KIRCHHOFF'S LAW

At a given temperature for all bodies the ratio of their spectral emissive power (e_λ) to spectral absorptive power (a_λ) is constant and this constant is equal to spectral emissive power (E_λ) of the ideal black body at same temperature

$$\boxed{\underset{GB}{\frac{e_\lambda}{a_\lambda}} = \underset{IBB}{E_\lambda}} = \text{constant} \qquad \left(\frac{e_\lambda}{a_\lambda}\right)_1 = \left(\frac{e_\lambda}{a_\lambda}\right)_2 = \text{constant}$$

$\boxed{e_\lambda \propto a_\lambda}$ **Imp.**

KEY POINTS ABOUT KIRCHOFF LAW

1. For a constant temperature the spectral emissive power of an ideal black body is a constant parameter
2. The practical confirmation of Kirchhoff's law carried out by **Rishi apparatus** & the main base of this apparatus is a **Lessilie container.**
3. The main conclusion predicted from Kirchhof's law can be expressed as

Good absorber	$\rightleftharpoons$	Good emitter
Bad absorber	$\rightleftharpoons$	Bad emitter
(at Low temperature)		(at High temperature)

Specific Applications of Kirchoff Law -

(i) Fraunhoffer's lines :

Fraunhoffer lines are **dark lines** in the spectrum of the sun. When white light emitted from the central core of the sun (Photosphere) passes. Through its atmosphere (Chromosphere) radiations of those wavelengths will be absorbed by the gases present, resulting in **dark lines** in the spectrum of sun.

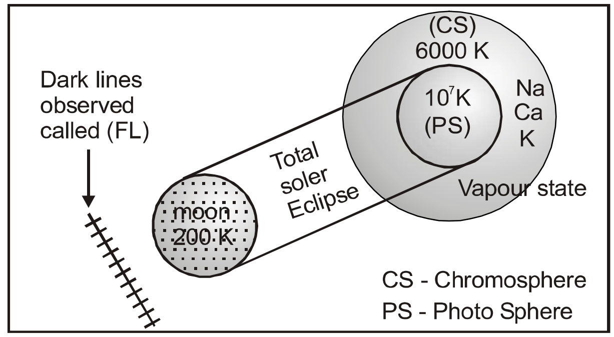
At the time of **total solar eclipse** direct light rays emitted from photosphere cannot reach on the earth and only rays from chromosphere are able to reach on the earth surface. At that time we observe **bright** fraunhoffer lines.

(a) During Normal Condition :-

– Dark lines N_D (Number)

– Absorption spectra

(b) Total Solar Eclipse :



(At time of total Solar Eclipse surface area of moon totaly covers the photosphere)

– Bright lines N_B (Number)

– Emission spectra, (Always $N_D = N_B$)

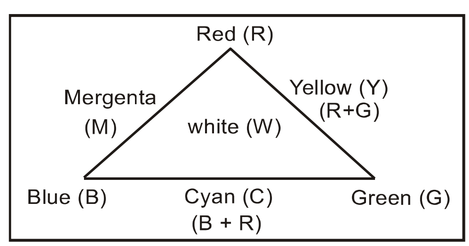
(ii) (a) **Sand** is **rough** and **black**, so it is a good absorber and hence in deserts, days (When radiation from sun is incident on sand) will be very hot. Now in accordance with Kirchhoff's Law, good absorber is a good emitter. So nights (when send emits radiation) will be cold. **That is why in deserts days are hot and nights cold.**

(b) Above same concept is applied to

(iii) Colour Triangle

Primary Colour $\rightarrow$ The colour present in the spectrum which when passed through a prism do not get dispersed.

Complementary Colour $\rightarrow$ Those two colour present in the spectrum which when mixed produce white light.



$C + Y + M = \text{White}$ $\quad G + R \rightarrow \text{Sunlight (Yellow)}$

$B + Y \rightarrow \text{White}$ $\quad Y + M \rightarrow \text{Red}$

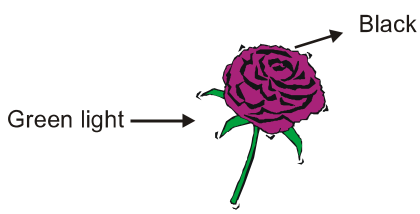
KEY POINTS

1. Green body appears green because it reflects or transmits green and absorbs all colours.
2. When a green body is heated in a dark room then it appears red (or vice versa).

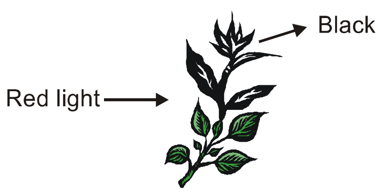
$\boxed{\text{Red} \rightleftharpoons \text{Green}}$ $\boxed{\text{Yellow} \rightleftharpoons \text{Blue}}$

A red body absorbs green light strongly at room temperature .When it is heated, it emits green light.

3. For a body, if it absorb specific colour radiations, if this radiations incident on given body in a dark room then it appears to be black (i.e. invisible)



Red rose



Green leaf

STEFAN'S LAW

The amount of radiation emitted per second per unit area by a black body is directly proportional to the fourth power of its absolute temperature.

$E \propto T^4$ $\left[\begin{array}{l} T = \text{Temperature of IBB (in K)} \\ E = \text{Amount of emitted radiation} \end{array}\right]$

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

(i) Unit of E = watt/m²

(ii) σ = Stefen's constant and value of $\sigma = 5.67 \times 10^{-8}$ watt /m²k⁴ , dimension = $M^1L^0T^{-3}\theta^{-4}$

(iii) This law is true for only ideal black body.

(a) Prevost's concept is not applied :–

Total radiation energy emitted out by IBB surface of area A in time t is given by

$Q = EAt$ Joule $\qquad Q_{IBB} = \sigma A T^4 t$ Joule

$(e_r = Q_{GB}/Q_{IBB})$

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

(b) Prevost's concept is also applied :–

When Temperature of surrounding T_0 (Let $T_0 < T$)

Rate of emission of radiation from IBB surface

$E_1 = \sigma T^4$ J/m² sec.

Rate of emission of radiation from surrounding

$E_2 = \sigma T_0^4$ J/m² sec.

Net rate of loss of radiation from IBB surface must be $E = E_1 - E_2 = \sigma T^4 - \sigma T_0^4$

$E = \sigma (T^4 - T_0^4)$ J/m² sec.

Net loss of Radiation energy from entire surface area in time t is given by Q = EAt

$Q_{IBB} = \sigma A (T^4 - T_0^4)\, t$ Joule

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

$\boxed{Q_{GB} = e_r A\sigma (T^4 - T_0^4)\, t \text{ Joule}}$

Let in time dt the net heat energy loss for ideal BB is dQ and because of this its temperature falls by dθ.

$dQ = \sigma A(T^4 - T_0^4)\, dt$ Joules

$$\left[dQ = MS\, d\theta, \quad \frac{dQ}{dt} = M.S.\frac{d\theta}{dt}\right]$$

V. Imp. $\qquad$ **J = Joule**

Rate of loss of heat (R_H)	**Rate of fall in temperature (R_F)**
$\boxed{\frac{dQ}{dt} = \frac{e_r \sigma A}{J}(T^4 - T_0^4) \text{ Cal/ sec.}}$	$\boxed{\frac{d\theta}{dt} = \frac{e_r \sigma A}{MSJ}(T^4 - T_0^4)\ ^0\text{C/sec.}}$
$R_H = \frac{dQ}{dt}$ = Rate of loss of heat	$R_F = \frac{d\theta}{dt}$ = Rate of fall in temperature
= Emitted power	= which is cooling faster
= Emitted radiation per second	= Rate of cooling

Note:-

(i) If all of T, T_0, M, S, V, ρ, are same forr different shape body then R_F & R_H will be maximum in the flat surface.

(ii) If a solid and hollow sphere are taken with all the parameters same then hollow will cool down at fast rate.

(iii) Rate of temperature fall , $R_F \propto 1/S \propto d\theta/dt$ So, dt $\propto$ s

If condition in sp. heat is $\Rightarrow S_1 > S_2 > S_3$ It all cooled same temperature i.e. temperature fall is also identical for all then required time

$t \alpha S$

$\therefore t_1 > t_2 > t_3$

When a body cools by radiation the cooling depends on :–

(1) ***Nature of radiating surface*** $\Rightarrow$ greater the emissivity (e_r), faster will be the cooling.

(2) ***Area of radiating surface,*** $\Rightarrow$ greater the area of radiating surface, faster will be the cooling.

(3) ***Mass of radiating body,*** $\Rightarrow$ greater the mass of radiating body slower will be the cooling.

(4) ***Specific heat of radiating body*** $\Rightarrow$ greater the specific heat of radiating body slower will be the cooling.

(5) ***Temperature of radiating body,*** $\Rightarrow$ greater the temperature of radiating body faster will be the cooling.

Solved Examples

Ex.3 Find out ratio of rate of loss of heat and rate of fall in temperature. (different body A cube, Sphere and Cylinder) (For Given Dimensions)

Body	Area(A)	Volume	(V) A/V	Result
Sphere(R)	$4\pi R^2$	$\frac{4}{3}\pi R^3$	$\frac{3}{R}$	$\because R_H \alpha A - \left[\begin{array}{l}\text{Max for sphere \& cylinder}\\ \text{Min for cube}\end{array}\right.$
Cube (R)	$6R^2$	R^3	$\frac{6}{R}$	and $R_F \alpha \frac{A}{V} - \left[\begin{array}{l}\text{Max for cube}\\ \text{Min for sphere}\end{array}\right.$
Cylinder (ℓ=R)	$\frac{4\pi R^2}{(2\pi R\ell + R\pi R^2)}$	πR^3	$\frac{4}{R}$	

Ex.4 If temperature of IBB is increased by 50%, what will be % increase in Quantity of radiations emitted from its surface.

Sol. IMP. $E \alpha T^4$ and $\therefore E' \alpha (1.5)^4 T^4$

$\propto \left(\frac{15}{10}\right)^4 T^4 \propto \left(\frac{3}{2}\right)^4 T^4 \propto \frac{81}{16} T^4 \propto 5T^4$

$\frac{E'-E}{E} \times 100\% = \left(\frac{5T^4 - T^4}{T^4}\right) \times 100\% = 400\%$

Ans. increase by 400%

Ex.5 If temperature of IBB is decrease by T to T/2 than worked out percentage loss in emissive rate

Sol. $E \alpha T^4$, $E' \alpha \left(\frac{T}{2}\right)^4 \Rightarrow \frac{T^4}{16}$

Remaining is 6% (Approx.)

$\left(\frac{E - E'}{E}\right) \times 100\% = \left(1 - \frac{1}{16}\right) \times 100\%$

$= \frac{15}{16} \times 100\% \Rightarrow 94\%$ **Ans.**

Ex.6 Calculate the energy radiated per second from the filament of an incandescent lamp at 2000K, if the surface area is 5.0×10^{-5} m^2 and its relative emittance is 0.85 & $\sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-4}.

Sol. Given $A = 5.0 \times 10^{-5}$ m^2,

$\sigma = 5.7 \times 10^{-8}$ W m^{-2} K^{-4}, e = 0.85, T = 2000 K.

We know, $E = Ae_r\sigma T^4$

$E = 5.0 \times 10^{-5}\ m^2 \times 0.85 \times 5.7 \times 10^{-8}$

$W\ m^{-2}\ K^{-4} \times (2000)^4\ K^4$

$E = 38.76\ W = 38.76\ J\ s^{-1}$

Ex.7 Calculate the temperature at which a perfect black body radiates at the rate of $5.67\ W\ cm^{-2}$. Stefan's constant is $5.67 \times 10^{-8}\ J\ s^{-1}\ m^{-2}\ K^{-4}$.

Sol. Given $E = 5.67\ W\ cm^{-2} = 5.67 \times 10^{+4}\ W\ m^{-2}$

$\sigma = 5.67 \times 10^{-8}\ J\ s^{-1}\ m^{-2}\ K^{-4}$

Using, $E = \sigma T^4$; $T^4 = \dfrac{E}{\sigma}$ or $T = \left(\dfrac{E}{\sigma}\right)^{1/4}$

$= \left(\dfrac{5.67 \times 10^{-8}}{5.67 \times 10^{+4}}\right)^{1/4} = (10^{12})^{1/4} = 1000$ K. **Ans.**

NEWTON'S LAW OF COOLING

RATE OF COOLING :– Rate of cooling $(d\theta/dt)$ is directly proportional to excess of temperature of the body over that of surrounding. (when $(\theta - \theta_0) \ngtr 35^\circ C$**)**

Rate of cooling $\dfrac{d\theta}{dt} \propto (\theta - \theta_0)$

$$\left\{\begin{array}{l} \theta \to \text{temperature of body [in °C]} \\ \theta_0 \to \text{temperature of surrounding} \\ \theta - \theta_0 \to \textbf{excess of temperaure } (\theta > \theta_0) \end{array}\right\}$$

If the temperature of body decrease $d\theta$ in time dt then rate of fall of temperature

$$\frac{d\theta}{dt} = -K'(\theta - \theta_0) \qquad \left\{K' = \frac{4 e_r A\sigma\theta_0^3}{MS}\right\}$$

where negative sign indictates that the rate of cooling is decreasing with time.

$$\theta_1 \xrightarrow[t]{\text{temp. falls to}} \theta_2, \qquad \theta = \frac{\theta_1 + \theta_2}{2}$$

This is called radiation correction,

$$\boxed{\left(\frac{\theta_1 - \theta_2}{t}\right) = +K'\left(\frac{\theta_1 + \theta_2}{2} - \theta_0\right)} \quad \textbf{Imp.}$$

Limitations of Newton's Law :–

(i) Temperature diffrence should not exceed 35° C, $[(\theta - \theta_0) \ngtr 35°\ C]$

(ii) loss of heat sould only be by radiation.

(iii) This law is an extended form of Stefan–Boltzman's law.

For Heating, Newton's law of heating :–

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

H now called as heating constant.

Derivation of Newton's law from SBL :-

$$\frac{d\theta}{dt} = \frac{e_r\sigma A}{MS\ J}(T^4 - T_0^4) \qquad \left\{\begin{array}{l} T - T_0 = \Delta T \\ T = T_0 + \Delta T \\ \Delta T <<< T_0 \end{array}\right\}$$

$$\frac{d\theta}{dt} = \frac{e_r\sigma A}{MS\ J}\left[(T_0 + \Delta T)^4 - T_0^4\right]$$

If x <<< 1 then $(1+x)^n = 1+nx$

$$\frac{d\theta}{dt} = \frac{e_r\sigma A}{MS\ J}\left[T_0^4\left(1 + \frac{\Delta T}{T_0}\right)^4 - T_0^4\right]$$

$$\frac{d\theta}{dt} = \frac{e_r\sigma A}{MS\ J}T_0^4\left[\left(1 + \frac{\Delta T}{T_0}\right)^4 - 1\right]$$

$$\Rightarrow \frac{d\theta}{dt} = \frac{e_r\sigma A}{MS\ J}T_0^4\left(1 + 4\frac{\Delta T}{T_0} - 1\right)$$

$$\frac{d\theta}{dt} = \left[4\frac{e_r\sigma A}{MS\ J}T_0^3\right]\Delta T, \qquad \Rightarrow \frac{d\theta}{dt} = K\Delta T$$

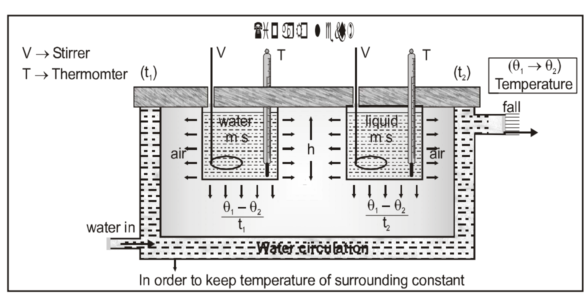
$$\left\{K = \frac{4 e_r \sigma A T_0^3}{MS\ J}\right.$$

$$\boxed{\frac{d\theta}{dt}\alpha\Delta T \quad \textbf{Newton's law}}$$

Imp. Application of Newton's law of cooling :-

To find out specific heat of a given liquid.

Key concept :– If for the two given liquids their **volume, radiating surface area, nature of surface, initial temperature** are allowed to cool down in a **common environments** then **rate of loss of heat** of these liquids are equal.



From Key concept loss of heat

$$\left(\frac{dQ}{dt}\right)_{Water} = \left(\frac{dQ}{dt}\right)_{Liquid}$$

$$\left(M_1S_1+W_1\right)\left(\frac{\theta_1-\theta_2}{t_1}\right) = \left(M_2S_2+W_2\right)\left(\frac{\theta_1-\theta_2}{t_2}\right)$$

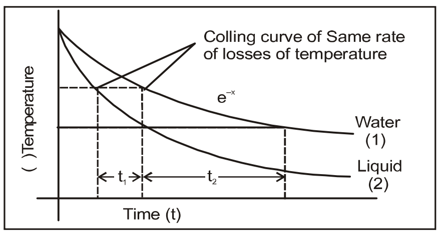
Imp. W = water equivalent of calorimeter.

$$\left(\frac{M_1S_1+W_1}{t_1}\right) = \left(\frac{M_2S_2+W_2}{t_2}\right)$$

Unit W = gm

Mass $\qquad\qquad$ M = Vρ

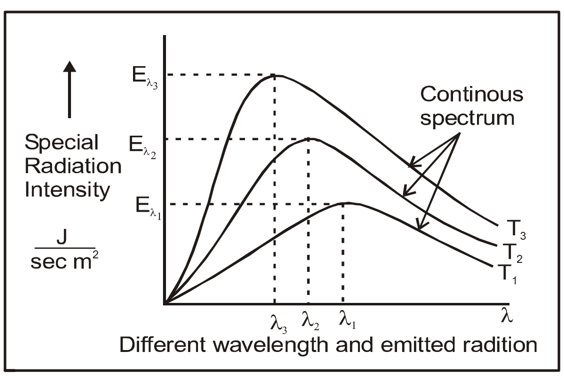
Cooling Curve

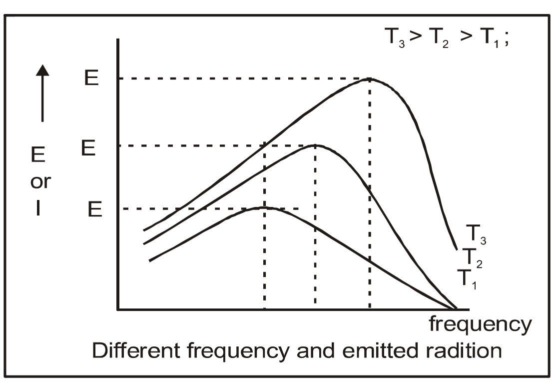


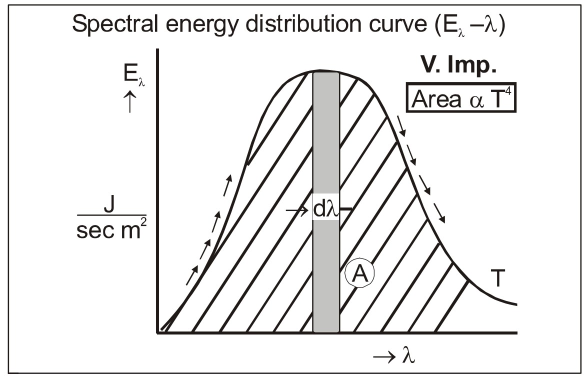
Spectral Energy distribution curve of Black Body radiations

Practically given by r **Lumers & Pringshem**

Mathematically given by r **Plank's**







Result :

(i) $T \propto \frac{1}{\lambda_m}$ $\qquad$ (ii) $E_{\lambda_m} \propto T^5$

(iii) Area $= \int_0^\infty E_\lambda d\lambda = E = \sigma T^4$ $\boxed{\frac{A_1}{A_2} = \left(\frac{T_1}{T_2}\right)^4}$

KEY POINTS

1. The curves drawn at various black body temperatures between the intensity of radiation and their wavelength or frequency are known as **spectral energy distribution curves**.
2. I.B.B. spectrum is a **continuous emission** spectrum and energy distribution in it depends only on the absolute temperature of black body.
3. As the wave length increases, the amount of radiation emitted first increase, becomes maximum and then decreases.
4. At a particular temperature the area enclosed between the spectral energy curve shows the spectral emissive power of the body.

$$\text{Area} = \int_0^\infty E_\lambda d\lambda = E = \sigma T^4$$

WEIN'S LAW

1. **Wein's Displacement Law :** The wavelength corresponding to maximum emission of radiation decrease with increasing temperature[$\lambda_m \propto 1/T$]. This is known as Wein's displacement law.

$\boxed{\lambda_m T = b}$ where b = Wein's constant,

(b = 2.93 x 10^{-3} m. kelvin)

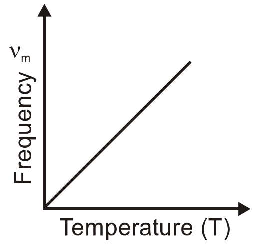
dimension of b = $M^0 L^1 T^0 \theta^1$

Relation between frequency & temperature :

$\boxed{\nu_m \propto T}$

$\nu_m = b'T,$

$\frac{C}{\lambda_m} = b'T$

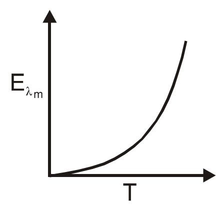


2. **Wein's 5th power Law and energy distribution law :-** The maximum amount of radiation emitted by the black body at wavelength (λ_m) is directly proportional to the fifth power of the temperature This is known as **Wein's energy distribution law.**

$\boxed{E_{\lambda_m} \propto T^5}$ $T\uparrow \Rightarrow \lambda_m\downarrow \Rightarrow E_{\lambda_m}\uparrow$

$E_{\lambda_m} \Rightarrow$ **maximum Emissive power** $\propto T^5$ (Imp.)

$E \Rightarrow$ **Total Emissive power** $\propto T^4$



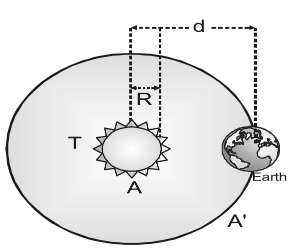
Applications of Wein's Law :-

1. To compare temperature of given stars by observing their colour because colour of star identify its temperature. $T_B > T_W > T_R$
2. The temperature developed by explosion of atomic bomb can be worked out.

$\lambda_m = 5.2Å$, then T = ? **Ans.** 10^7K

SOLAR CONSTANT 'S'

The sun emits radiant energy continuously in space of which an in significant part



reaches the earth. The solar radiant energy received per unit area per unit time by a black surface held at right angles to the sun's rays and placed at the mean distance of the earth (in the absence of atmosphere) is called solar constant.

The solar constant S is taken to be 1340 watts/ m^2 . Temperature of the sun :–

Let R be the radius of the sun and 'd' be the radius of Earth's orbit around the sun. Let E be the energy emitted by the sun per second per unit area. Then, the total energy emitted by the sun in one second $= E.A = E \times 4\pi R^2$.

(This energy is falling on a sphere of radius equal to the radius of the Earth's orbit around the sun i.e., on a sphere of surface area $4\pi d^2$)

So, The energy falling per unit area of earth

$$= \frac{4\pi R^2 \times E}{4\pi d^2} = \frac{E\,R^2}{d^2}$$

By definition, this is the solar constant S

i.e., $S = \frac{E\,R^2}{d^2}$

But $E = \sigma T^4$ According to Stefan's Law

$$S = \frac{\sigma T^4 R^2}{d^2} \text{ or } T^4 = \frac{S d^2}{\sigma R^2} \quad \text{or} \quad T = \left(\frac{S \times d^2}{\sigma \times R^2}\right)^{\frac{1}{4}}$$

Now $S = 1340\ Wm^{-2} = 1.4\ KWm^{-2}$,

$= 1.94$ cal/min. $cm^2 \simeq 2$ cal/min. cm^2

On substituting these values above we get T, the surface temperature of the sun. It comes out to be equal to 5791 K.

In this way, the surface temperature of sun has been estimated.

Increasing order of Planets distance with respect to Sun :-

Nearest :-

(1) Mercury - (Smallest)	(2) Venus
(3) Earth	(4) Mars
(5) Jupiter - (Biggest)	(6) Sacurn
(7) Uranus	(8) Neptune

(II) THERMAL CONDUCTION

* The process by which heat is transferred from hot part to cold part of a body through the transfer of energy from one particle to another particle of the body without the actual movement of the particles from their equilibrium positions is called conduction.
* The process of conduction only in solid body (except Hg)
* Heat transfer by conduction from one part of body to another continues till their temperatures become equal.

Variable state : It is the state in which temperature of each cross section of the rod increases with temperature but temperature of any cross-section of the rod decreases with incrreasing distance from hot end to cold end.

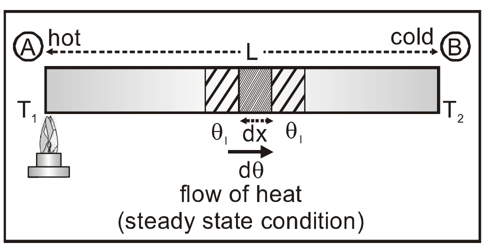
Steady state : When temperature of the each cross-section of the bar becomes constant but different for different cross-sections area is called thermal steady state.

Diffusivity : The ratio thermal conductivity to thermal capacity per unit volume of a material is called diffusivity.

$$D = \frac{k}{\rho s}$$

It is measure of rate of change of temperature when the body is not in steady state.

* **Equation of thermal conduction :**



$\boxed{\frac{dQ}{dt} = -KA\left(\frac{dT}{dX}\right)}$ $\boxed{\frac{dQ}{dt} = \frac{KA}{L}(T_1 - T_2)}$ **(V . Imp.)**

where dQ/dt $\Rightarrow$ rate of Heat flow

dT/dX $\Rightarrow$ Temperature Gradient, This is vector quantity (unit °C/m)

A $\Rightarrow$ cross section area

L $\Rightarrow$ Length (In heat flow dirction)

K $\Rightarrow$ Thermal conductivity of material

* **Temperature gradient. –**

The decrease in temperature with distance from hot end of the rod is known as temperature gradient.

It is denoted by $-\frac{dT}{dx}$ or In the direction of heat energy flow, the rate of fall in temperature w.r.t. distance is called as Temperaure gradient.

* **Thermal conductivity (K) –** It's depends on nature of material.
  - The order of thermal conductivity in $Ag > Cu > Au > Al$
  - Unit of (K) $\rightarrow JS^{-1}\,m^{-1}\,K^{-1}$, and dimension $- M^1L^1T^{-3}\theta^{-1}$

    max. for Ag (410 W/mk)
  - K $\rightarrow$ max. for Ag (410 W/mk); $\rightarrow$ min. for Freon –12(0.008 W/mk)

KEY POINTS

(a) For an ideal or perfect conductor of heat the value of $K = \infty$

(b) For an ideal or perfect bad conductor or insulator the value of $K = 0$

(c) **Imp.** For cooking the food, low sp. heat and high conductivity utensil is most suitable.

APPLICATION OF THERMAL CONDUCTION

* In winter, the iron chairs appear to be colder than the wooden chairs.
* Cooking utensils are made of aluminium and brass whereas their handles are made of wood.
* Ice is covered in gunny bags to prevent melting of ice.
* We feel warm in woollen clothes.
* Two thin blankets are warmer than a single blanket of double the thickness.

* We feel warmer in a fur coat.

* Birds often swell their feathers in winter.

* A new quilt is warmer than old one.

Note : **Air is bad conductor of heat**

Weidamann – Fronz – lorentz law :–

At a given temperature the ratio of thermal conductivity to electrical conductivity is constant.

$\boxed{K / \sigma T = \text{const.}}$

$\boxed{\begin{array}{l} K \uparrow \Rightarrow \sigma \uparrow \\ K \downarrow \Rightarrow \sigma \downarrow \end{array}}$

$K \rightarrow$ Thermal conductivity
$\sigma \rightarrow$ Electrical conductivity
$T \rightarrow$ Absolute temperature

Ingen Hausz Experiment :–

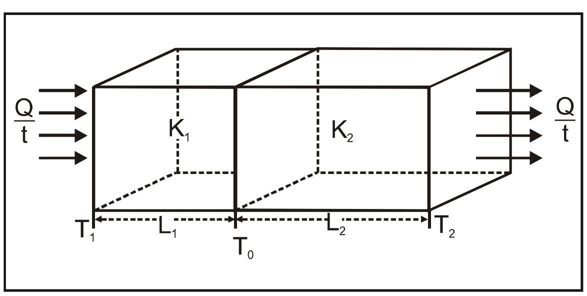
If several rods of different thermal conductivities are coated with wax and the one end of all these rods are maintained at the same temperature, then the lengths of the rods upto which wax has melted is proportional to the square roots of $\frac{\ell_1}{\ell_2} = \sqrt{\frac{K_1}{K_2}}$

Thermal Resistance (R) :– The thermal resistance of a body is a measure of its opposition of the flow of heat through it.

$\boxed{R = \frac{L}{KA}}$ **(Imp.)**

(a) Heat flow through slabs in series : Than equivalent thermal conductivity of the system is

$R_e = R_1 + R_2$

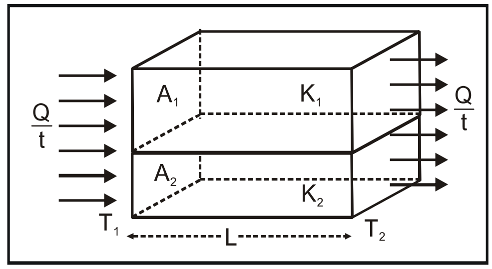


$$\frac{L_1 + L_2}{K_e A} = \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A}$$

$$K_e = \frac{L_1 + L_2}{L_1 / K_1 + L_2 / K_2} = \frac{\Sigma Li}{\Sigma \frac{Li}{Ki}}$$

(b) Heat flow through slabs in parallel :

Than equivalet thermal conductivity.



$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} \qquad R = \frac{L}{KA}$$

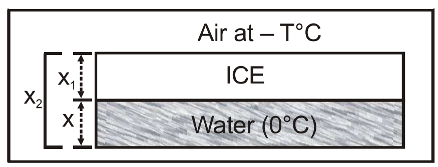
$$\frac{K_e}{L}(A_1 + A_2) = \frac{K_1 A_1}{L} + \frac{K_2 A_2}{L}$$

$$K_e = \frac{K_1 A_1 + K_2 A_2}{A_1 + A_2} = \frac{\Sigma KiAi}{\Sigma Ai}$$

Growth of Ice of Lakes :–

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

Heat $dQ = mL$ and $m = v\rho = A.x.\rho$



$$\frac{\rho AxL}{dt} = -KA\frac{dT}{dx}$$

$$dt = -\frac{\rho L}{KdT} xdx \qquad \text{taking intregation}$$

$$\int_{t_1}^{t_2} dt = -\frac{\rho L}{KdT}\int_{x_1}^{x_2} xdx$$

$$t_2 - t_1 = \frac{1}{2}\frac{\rho L}{KT}(x_2^2 - x_1^2),$$

$$\boxed{t = \frac{1}{2}\frac{\rho L}{KT}(x_2^2 - x_1^2)} \quad \text{and} \quad t \propto (x_2^2 - x_1^2)$$

* Time taken to double and triple the thickness ratio

$t_1 : t_2 : t_3 \quad :: 1^2 : 2^2 : 3^2$

so $\quad :: 1 : 4 : 9$

Solved Examples

Ex.8 One end of a brass rod 2m long and having 1 cm radius is maintained at 250°C. When a steady state is reached, the rate of heat flow across any cross–section is 0.5 cal S^{-1}. What is the temperature of the other end $k = 0.26$ cal s^{-1} cm^{-1} $°C^{-1}$.

Sol. $\frac{Q}{t} = 0.5$ cal s^{-1}; r = 1 cm

$\therefore$ Area $A = \pi r^2 = 3.142 \times 1\ cm^2 = 3.142\ cm^2$

L = Length of rod = 2m = 200 cm,

$T_1 = 250°C$, $T_2 = ?$

We know $\frac{Q}{t} = \frac{KA(T_1 - T_2)}{L}$

or $(T_1 - T_2) = \frac{Q}{t} \times \frac{\Delta x}{kA}$

$= \frac{0.5\ cal\ s^{-1} \times 200\ cm}{0.26\ cal\ s^{-1}\ °C^{-1} \times 3.142\ cm^2} = 122.4°C$

$\therefore T_2 = 250°C - 122.4°C = 127.6°C$

Ex.9 Steam at 373 K is passed through a tube of radius 10 cm and length 2 m. The thickness of the tube is 5 mm and thermal conductivity of the material is 390 W m^{-1} K^{-1}, calculate the heat lost per second. The outside temperature is 0°C.

Sol. Using the relation $Q = \frac{KA(T_1 - T_2)t}{L}$

Here, heat is lost through the cylindrical surface of the tube.

A = $2\pi r$ (radius of the tube) (length of the tube)

$= 2\pi \times 10\ cm \times 2\ m$

$= 2\pi \times 0.1 \times 2m^2 = 0.4\ \pi m^2$

K = 390 W m^{-1} K^{-1}

$T_1 = 373$ K, $T_2 = 0°C = 273$ K,

L = 5 mm = 0.005 m and t = 1 s

$\therefore Q = \frac{390\ W\ m^{-1} \times 0.4\pi m^2 \times (373 - 273)\ K \times 1s}{0.005\ m}$

$= \frac{390 \times 0.4\pi \times 100}{0.005}$ Ws $= 98 \times 10^5$ J.

Ex.10 The thermal conductivity of brick is 1.7 W m^{-1} K^{-1}, and that of cement is 2.9 W m^{-1} K^{-1}. What thickness of cement will have same insulation as the brick of thickness 20 cm.

Sol. Since $Q = \frac{KA(T_1 - T_2)t}{L}$

For same insulation by the brick and cement Q, A $(T_1 - T_2)$ and t do not change.

That is, $\frac{K}{L}$ shoule be a constant.

Thus, if K_1 and K_2 be the thermal conductivities of brick and cement and L_1 and L_2 be the required thickness then :

$\frac{K_1}{L_1} = \frac{K_2}{L_1}$ or $\frac{1.7\ W^{-1}\ K^{-1}}{20\ cm} = \frac{2.9\ W\ m^{-1}\ K^{-1}}{L_2}$

$\therefore L_2 = \frac{2.9}{1.7} \times 20$ cm = 34.12 cm.

Ex.11 Two vessels of different material are identical in size and wall–thickness. They are filled with equal quantities of ice at 0°C. If the ice melts completely, in 10 and 25 minutes respectively then compare the coefficients of thermal conductivity of the materials of the vessels.

Sol. Let K_1 and K_2 be the coefficients of thermal conductivity of the materials,

and t_1 and t_2 be the time in which ice melts in the two vessels.

Since both the vessels are identicel, so A and x in both the cases is same.

Now

$Q = \frac{K_1 A(\theta_1 - \theta_2)t_1}{L} = \frac{K_2 A(\theta_1 - \theta_2)t_2}{L}$

or $K_1 t_1 = K_2 t_2$ or $\frac{K_1}{K_2} = \frac{t_2}{t_1} = \frac{25\ min}{10\ min} = .\frac{5}{2}$

Ex.12 Two plates of equal areas are placed in contact with each other. Their thickness are 2.0 cm and 5.0 cm respectively. The temperature of the external surface of the first plate is –20°C and that of the external surface of the second plate is 20°C. What will be the temperature of the contact surface if the plate (i) are of the same material, (ii) have thermal conductivities in the ratio 2 : 5.

Sol. Rate of flow of heat in the plates is

$$\frac{Q}{t} = \frac{K_1A(\theta_1 - \theta)}{L_1} = \frac{K_2A(\theta - \theta_2)}{L_2} \quad ....(1)$$

(i) Here $\theta_1 = -20°C$, $\theta_2 = 20°C$

$L_1 = 2$ cm = 0.02 m, $L_2 = 5$ cm = 0.05 m.

$K_1 = K_2 = K$.

$\therefore$ eqn. (1) becomes

$$\frac{KA(-20-\theta)}{0.02} = \frac{KA(\theta - 20)}{0.05}$$

$\therefore$ $5(-20-\theta) = 2(\theta - 20)$

$-100 - 5\theta = 2\theta - 40$

$7\theta = -60 \qquad \theta = -8.6°C.$

(ii) $\frac{K_1}{K_2} = \frac{2}{5}$ or $\quad K_1 = \frac{2}{5}K_2$

$\therefore$ eqn (1) becomes

$$\frac{2/5\,K_2A(-20-\theta)}{0.02} = \frac{K_2A(\theta - 20)}{0.05}$$

$-20 - \theta = \theta - 20$ or $\quad -2\theta = 0$

$\therefore$ $\theta = 0°C$

Ex.13 An ice box used for keeping eatables cold has a total wall area of 1 metre^2 and a wall thickness of 5.0 cm. The thermal conductivity of the ice box is K = 0.01 joule/metre–^{0}C. It is filled with ice at 0°C along with eatables on a day when the temperature is 30°C. The latent heat of fusion of ice is 334×10^3 jules/kgm. The amount of lice melted in one day is (1 day = 86,400 seconds)

Sol. $\frac{dQ}{dt} = \frac{KA}{L}d\theta = \frac{0.01 \times 1}{0.05} \times 30 = 6$ joule@sec.

Q = 518400 joule]

Q = mL (L - latent heat)

Ans. = m = 1552 gm.

(III) CONVECTIONS

(i) The mode of heat transfer due to density difference in fluids (liquid + gas) is known as convection.

(ii) In this process, transfer of heat by actual motion of particles of medium from one place to another.

(iii) Based on gravity when zero gravity region than No convection.

e.g. Centre of earth, where g = 0, so No convection.

Two types of Convection :–

(a) **Natural convection** $\rightarrow$ (lang – Muir & Lorentz Law)

* Earth air, Water air etc.

* $\frac{dQ}{dt} \propto (\theta - \theta_0)^{5/4}$ [1¼]

(b) **Force convection** $\rightarrow$

* Newton's law of cooling is applicable.

* $\frac{dQ}{dt} \propto (\theta - \theta_0)$

KEY POINTS

(i) For heat propagation via convection, temperature gradient exists in vertical direction and not in horizontal direction.

(ii) Most of heat transfer that is taking place on earth is by convection, the contribution due to conduction and radiation is very small.

Sp. Example Convection :

* Cold air flow from ocean to ground to earth.
* The upper Layers of atmosphere are heated.