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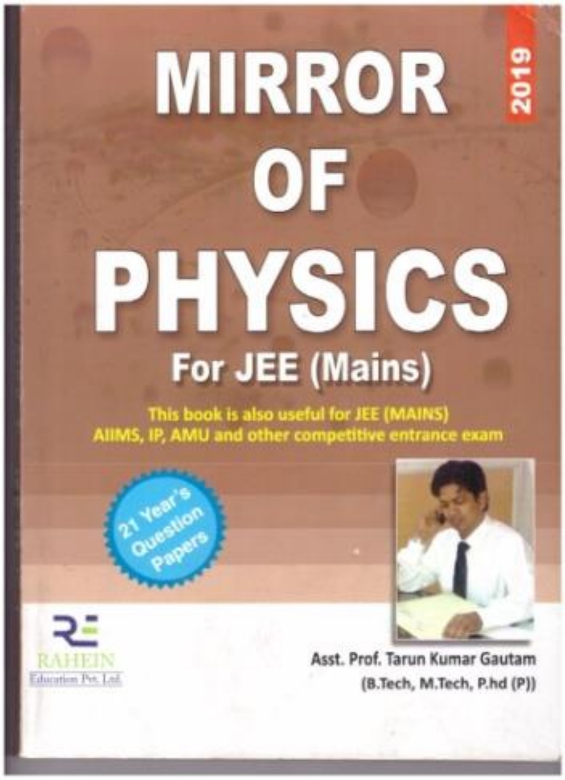
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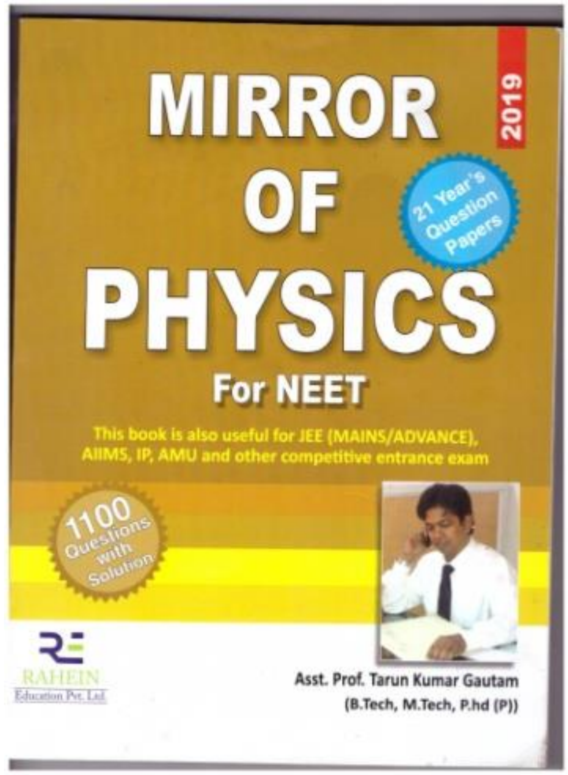
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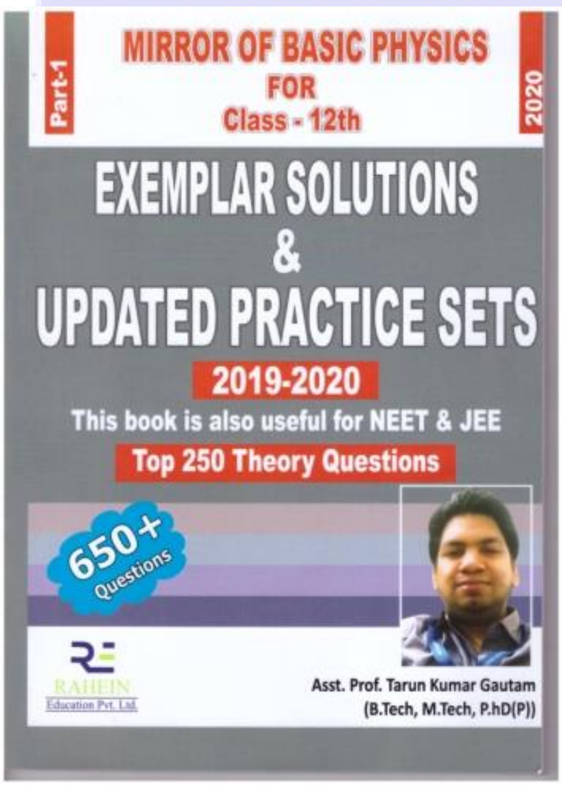
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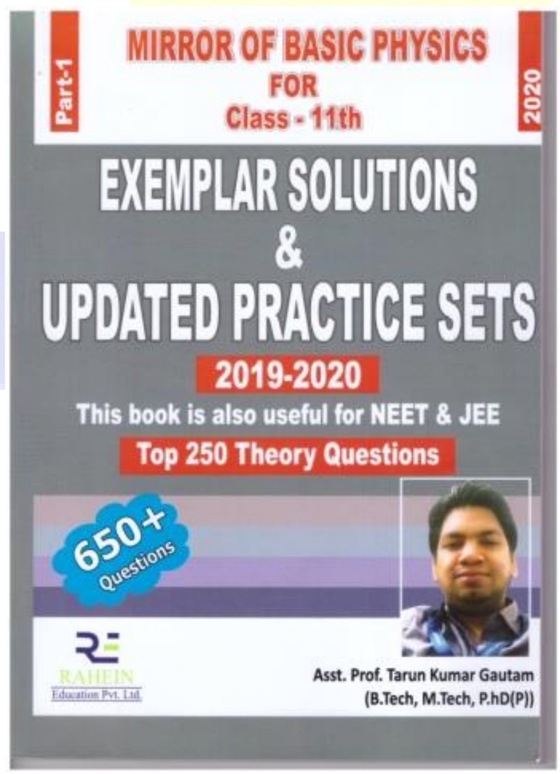
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Chapter - 11

"Thermal Properties of Matter"

Heat : It is a form of energy which produce in us the sensation of warmth.

Unit of Heat is joule (J) [S.I unit]
C.g.s unit → calorie

$$\boxed{1 \text{ cal} = 4.186 \text{ J}}$$

Temperature : Temperature of a body as degree of hotness or coldness of body.

$$\boxed{\frac{T_C - 0}{100} = \frac{T_f - 32}{180} = \frac{T_K - 273.15}{100}}$$

where, T_C → Celcius, T_f → farhaniet, T_K → Kelvin

Ex - $T_C = 20°C$. Convert into Faranheit ?

$$\Rightarrow \frac{20 - 0}{100} = \frac{T_f - 32}{180}$$

$$\frac{20 \times 180}{100} + 32 = T_f$$

$$36 + 32 = T_f$$

$$\boxed{68°F = T_f}$$

Thermal Expansion :
1) Linear expansion
2) Area expansion
3) Volume expansion

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1) **Linear Expansion** : It is change in length due to heat.

$\rightarrow \Delta L \propto L(\Delta T)$

$\rightarrow \boxed{\Delta L = \alpha L(\Delta T)}$

where, $\Delta T \rightarrow$ change in Temp.
$L \rightarrow$ Length
$\Delta L \rightarrow$ change in Length
$\alpha \rightarrow$ coefficient of Linear expansion

2) **Area Expansion**: It is change in area due to heat

$\longrightarrow \Delta S \propto (S)(\Delta T)$

$\longrightarrow \boxed{\Delta S = \beta(S)(\Delta T)}$

where, $\Delta S \rightarrow$ change in Surface
$S \rightarrow$ Surface
$\Delta T \rightarrow$ Change in Temp.
$\beta \rightarrow$ coefficient of Area expansion.

3) **Volume Expansion** : It is the change in volume due to heat.

$\rightarrow \Delta V \propto (V)(\Delta T)$

$\rightarrow \boxed{\Delta V = \gamma(V)(\Delta T)}$

where, $\Delta V \rightarrow$ change in volume
$V \rightarrow$ Volume
$\Delta T \rightarrow$ change in Temp.
$\gamma \rightarrow$ coefficient of volume expansion

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★ Relation Between α, β and γ

Length = L, $S = L^2$, volume(V) = L^3

$$\Delta L = \alpha \cdot L \cdot \Delta T \qquad \Delta S = \beta \cdot S \cdot \Delta T$$

$$\Delta V = \gamma \cdot V \cdot \Delta T$$

New length of cube = $L + \Delta L$
New Surface area of cube = $S + \Delta S$
New Volume of cube = $V + \Delta V$

Relation between (α) & (β) :

New Surface area $\Rightarrow$ $S + \Delta S = (L + \Delta L)^2$

$$S + \beta \cdot S \cdot \Delta T = (L + L \cdot \alpha \cdot \Delta T)^2$$

$$S[1 + \beta \cdot \Delta T] = L^2[1 + \alpha \Delta T]^2$$

$$\cancel{S}[1 + \beta \cdot \Delta T] = \cancel{S}[1 + \alpha \Delta T]^2$$

$$[1 + \beta \cdot \Delta T] = [1 + \alpha^2 \cdot \Delta T^2 + 2 \cdot \alpha \cdot \Delta T]$$

($\alpha^2 \cdot \Delta T^2$ → neglect)

$$\beta \cdot \cancel{\Delta T} = 2\alpha \cdot \cancel{\Delta T}$$

$$\beta = 2\alpha$$

$$\boxed{\alpha = \frac{\beta}{2}}$$

Relation between (α) & (γ) :

New Volume $\Rightarrow$ $V + \Delta V = (L + \Delta L)^3$

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$$(V + \gamma \cdot V \cdot \Delta T) = (L + L \cdot \alpha \cdot \Delta T)^3$$
$$V(1 + \gamma \cdot \Delta T) = L^3 (1 + \alpha \cdot \Delta T)^3$$
$$V(1 + \gamma \cdot \Delta T) = V(1 + \alpha \cdot \Delta T)^3$$
$$1 + \gamma \cdot \Delta T = 1^3 + \underbrace{\alpha^3 \Delta T^3}_{\text{neglect}} + 3\alpha\Delta T + 3\underbrace{(\alpha^2 \Delta T^2)}_{\text{neglect}}$$

$$1 + \gamma \cdot \Delta T = 1 + 3 \cdot \alpha \Delta T$$
$$\gamma \cdot \Delta T = 3\alpha \cdot \Delta T$$
$$\boxed{\alpha = \frac{\gamma}{3}}$$

As $\boxed{\frac{\beta}{2} = \alpha = \frac{\gamma}{3}}$

So, $\boxed{6\alpha = 3\beta = 2\gamma}$

Note :

1) Coefficient of real expansion of Liquid

→ $\gamma_r = \left[\frac{\text{real Increase in Volume}}{\text{original volume} \times \text{rise in Temp}}\right]$

2) Coefficient of apparent expansion of Liquid

→ $\gamma_a = \left[\frac{\text{apparent increase in volume}}{\text{original volume} \times \text{rise in Temp.}}\right]$

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Effect of Temp on density of Solid and Liquid:

At Temp. T_1 = ρ (Density)
At Temp. T_2 = ρ'

$$\rho' = \rho[1 - \gamma(\Delta T)]$$

γ = coefficient of Volume expand

Expansion of Gases :

$$PV = nRT \quad \text{--- (1)}$$
$$P\cdot(\Delta V) = nR(\Delta T) \quad \text{--- (2)}$$

Divide eqⁿ (2) by (1)

$$\frac{P(\Delta V)}{P\cdot V} = \frac{n \times R \times \Delta T}{n \times R \times T}$$

$$\frac{\Delta V}{V} = \frac{\Delta T}{T}$$

(Q) Specific heat Capacity or Specific heat

It is defined as amount of heat required to raise the temp of unit mass of substance through unit degree

$$\Delta Q = s \cdot m \cdot \Delta T$$

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where, S → Specific heat
m → mass
ΔT → change in Temp.
ΔQ → required Heat or change in Heat.

Unit → $s = \frac{\Delta Q}{m \cdot \Delta T} = \frac{Cal}{g \cdot C^{\circ}} \Rightarrow cal\, g^{-1} C^{\circ -1}$

$s = \frac{\Delta Q}{m \cdot \Delta T} \Rightarrow \frac{Cal}{kg \cdot K} \Rightarrow cal\, kg^{-1} K^{-1}$

$$\boxed{1\, cal = 4.2 J}$$

(b) Molar Specific heat or Molar heat capacity

→ It is defined as amount of heat required to raise the temperature of one gram Mole of Substance through one degree.

$$\boxed{C = Ms}$$

→ M → Molar mass

→ $\Delta Q = m \cdot s \cdot \Delta T \Rightarrow n = \frac{m}{M} \Rightarrow [m = n \times M]$

→ $S = \frac{\Delta Q}{m \cdot \Delta T} \Rightarrow \frac{\Delta Q}{(nM)(\Delta T)}$

$[Ms] = \frac{1}{n} \cdot \frac{\Delta Q}{\Delta T}$

$$\boxed{C = \frac{1}{n}\left[\frac{\Delta Q}{\Delta T}\right]}$$

Note:

$c/s \rightarrow$ specific heat

$C/S \rightarrow$ Molar specific heat

$$C = Ms$$

$$S = Ms$$

Note:

1) $\Delta Q = m \cdot s \cdot \Delta T$

$$C = M \cdot s$$

2) n = no of moles $= \frac{m}{M}$

$$m = n \times M$$

3) $C = \frac{1}{n}\left[\frac{\Delta Q}{\Delta T}\right]$

4) $s/c \rightarrow$ specific heat

C_p [specific heat at constant pressure]

C_v [specific heat at constant volume]

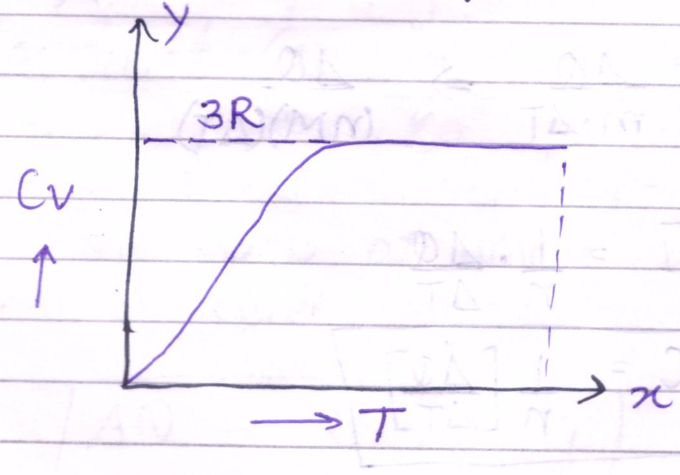
5) $R \rightarrow$ gas constant

$$PV = n \times R \times T$$

$$C_p - C_v = R$$

6) $\gamma = \frac{C_p}{C_v}$ (specific heat)

Variation of specific heat of a solid with Temperature



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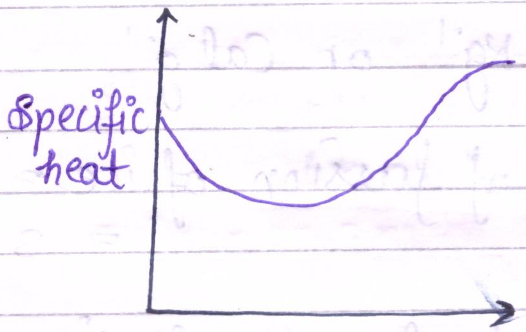
Specific Heat of water



Thermal Capacity of body

It is defined as amount of heat required to raise the Temp of whole body through 1°C or 1 K.

$$\Delta Q = m \cdot s \cdot \Delta T$$

Water Equivalent

It is defined as the mass of water in gram which would absorb or evolve same amount of heat as is done by body in rising or falling through the same range of temp. It represent by (W)

- Body ⟶ $\Delta Q = W \cdot (\Delta T)$ ---- (1)
- Water ⟶ $\Delta Q = m \cdot s \cdot (\Delta T)$ ---- (2)

Latent Heat

It is amount of heat energy required to change the state of unit mass of substance from solid to liquid or from liquid to gas/vapour without any change in Temp.

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$$Q = m \times L \rightarrow L = \frac{Q}{m}$$

Unit → $J\,Kg^{-1}$ or $Cal\,g^{-1}$

→ Latent heat of fussion of ice = $80\ cal\,g^{-1}$
= $3.33 \times 10^5\ J/kg$

→ Latent heat of vapourisation of water = $540\ cal\,g^{-1}$ = $22.6 \times 10^5\ J/kg$

Calorimeter

→ It is method of determination of specific heat/ Latent heat of a substance.
→ It uses a calorimeter which is cyclindrical vessel of copper provided with a stirrer and lid.

This method used in method of mixture.
Let w = water equivalent of calorimeter & stirrer
m_1 = mass of water
t_1 = initial Temp. of water & calorimeter
t_2 = Temp. of substance
s = specific heat of substance
t = common Temp.

rise in Temp of water & calorimeter = $(t - t_1)$
fall in Temp of substance = $(t_2 - t)$

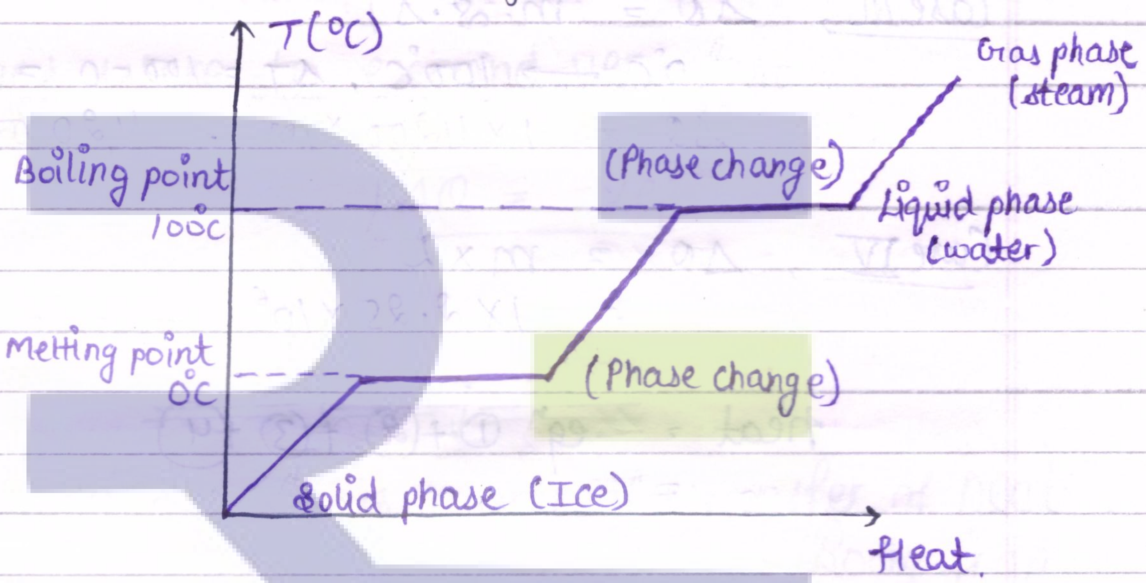
heat gained by water & calorimeter = $(m_1 + w)(t - t_1)$
heat lost by substance = $(s)(m_2)(t_2 - t)$

heat lost = heat gain

$$(s)(m_2)(t_2 - t) = (m_1 + w)(t - t_1)$$

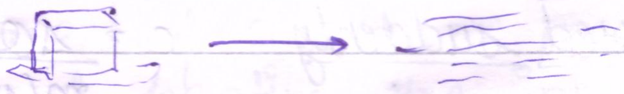
$$s = \frac{(m_1 + w)(t - t_1)}{(t_2 - t)}$$

Change of State



Ques Calculate the amount of heat required to convert 1 kg of Ice at −10°C into steam at 100°C at normal pressure.

Specific heat of Ice = $2100\ J\ Kg^{-1}\ K^{-1}$
Latent Heat of fusion of Ice = $3.36 \times 10^5\ J\ Kg^{-1}$
Specific heat capacity of water = $4200\ J\ Kg^{-1}\ K^{-1}$
Latent heat of vaporization of water is $2.25 \times 10^6\ J\ Kg^{-1}$



ice (−10°C) → steam (100°C)

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Case I, $\Delta Q = m \cdot s \cdot \Delta T$

$-10^\circ C \longrightarrow 0^\circ C$

$\Delta T = 0 - (-10) \Rightarrow +10$

$\Delta Q = 1 \times 2100 \times 10 \Rightarrow 21000\,J$ ——(1)

Case II, $\Delta Q = m \times L$

$\Delta Q = 1 \times 3.36 \times 10^5\,J$ ——(2)

Case III, $\Delta Q = m \cdot s \cdot \Delta T$

$0^\circ C \longrightarrow 100^\circ C,\ \Delta T = 100 - 0 = 100$

$\Delta Q = 1 \times 4200 \times 100 = 4,20,000\,J$ ——(3)

Case IV, $\Delta Q = m \times L$

$= 1 \times 2.25 \times 10^6$ ——(4)

heat = eqⁿ (1) + (2) + (3) + (4)

=

Specific heat of gas

It is amount of heat required to raise the temp of one gram through 1 degree

C → Speific heat of gas

$$\boxed{\Delta Q = C \cdot m \cdot \Delta T}$$

(a) Gas compressed suddenly $\quad C = \frac{\Delta Q}{m(\Delta T)}, \boxed{\Delta Q = 0}$

$$\boxed{C = 0}$$

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(b) Gas expand → $\Delta T = 0$, $c = \frac{\Delta Q}{m(\Delta T)} = \frac{\Delta Q}{0} = \infty$

$$\boxed{c = \infty}$$

(c) Rate of expansion of gas were slow

$\Delta T \rightarrow +ve$

$$\boxed{c \rightarrow +ve}$$

(d) If gas were to expand very fast

$\Delta T \rightarrow -ve$

$$\boxed{\Delta Q = -ve}$$

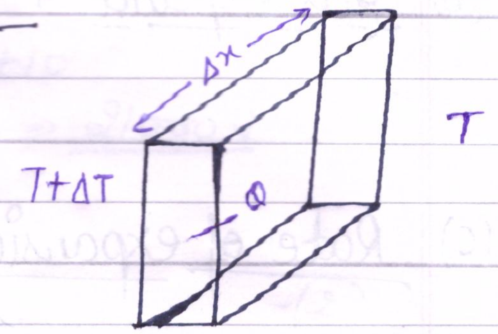
Transfer of heat

Conduction → It is made of transfer of heat from one part of Body to another Body from particle to particle in direction of fall of temperature without any actual movement of heated particle.

Convection → It is made of transfer of heat from one part of medium to another part by actual movement of heated particles of medium.

Radiation → It is made of transfer of heat from source to reciever without any actual movement of source or receiver and also without heating the inververing medium.

Thermal Conductivity



Let 'A' is area of hot face
→ Δx is distance between two faces
→ T → Temperure of cold face.
→ $T+\Delta T$ → is Temp of hot face.

Let $\frac{\Delta Q}{\Delta t}$ is rate of conduction of heat

→ $\frac{\Delta Q}{\Delta t} \propto A$

→ $\frac{\Delta Q}{\Delta t} \propto \Delta T$

→ $\frac{\Delta Q}{\Delta t} \propto \frac{1}{\Delta x}$

By combing the proportionalities

$$\frac{\Delta Q}{\Delta t} \propto \frac{A \cdot \Delta T}{\Delta x}$$

$$\boxed{\frac{\Delta Q}{\Delta t} = K\left[\frac{A \cdot \Delta T}{\Delta x}\right]}$$

K → coefficient of thermal conductivity

Unit → $\frac{\Delta Q}{\Delta t} = K\left[\frac{\Delta T}{\Delta x}\right] \times A$

$$\frac{\Delta Q}{\Delta t} \cdot \frac{\Delta x}{(\Delta T)(A)} = K$$

$$K = \frac{J}{sec} \times \frac{m}{K \times m^2}$$

$$= \left[\frac{J}{sec}\right]\frac{1}{K\cdot m} \Rightarrow watt \times K^{-1} \times m^{-1}$$

$$= J\,sec^{-1}K^{-1}m^{-1}$$

Newton's Law of Cooling

Rate of loss of heat of a Body is directly proportional to the difference in Temperature of Body and surrounding provided the difference in Temp is small, not more than 40°C.

Temp. of Body → T
Temp of surrounding → T_0

$\frac{dQ}{dt}$ → rate of change of heat

$$-\frac{dQ}{dt} \propto (T - T_0)$$

(-ve sign shows loss of heat)

$$\boxed{\frac{dQ}{dt} = -K(T - T_0)}$$

$\Delta T = T_2 - T_1$
if $T_1 = 0$
$T_2 = T$, $\boxed{\Delta T = T}$ $\Rightarrow$ $\boxed{Q = m.s.T}$

$$\frac{dQ}{dt} = -K \times (T - T_0)$$

$$\frac{d(m.s.T)}{dt} = -K \times (T - T_0)$$

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$$m \cdot s \cdot \frac{dT}{dt} = -K \times (T - T_0)$$

$$\frac{dT}{dt} = \frac{-K}{m \cdot s}(T - T_0)$$

$$\boxed{\frac{dT}{dt} = -k(T - T_0)} \quad \left[\because k = \frac{K}{ms} = \text{constant}\right]$$

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

Integrade Both side

$$\int_{T_1}^{T_2} \frac{dT}{(T - T_0)} = -\int k\,dt$$

$$\left[\log_e(T - T_0)\right]_{T_1}^{T_2} = -kt + c$$

$$\log_e(T_2 - T_0) = \log_e[T_1 - T_0] = -kt + c$$

$$\log_e\left[\frac{T_2 - T_0}{T_1 - T_0}\right] = -kt + c$$

$$\boxed{2.3026 \log_{10}\left[\frac{T_2 - T_0}{T_1 - T_0}\right] = -kt + c}$$

Stefan's Law

" It states that amount of heat (E) energy emitted per second by unit Area of a perfectly Black Body is directly proportional to forth power of absolute Temperature (T) of Body.

$$E \propto T^4$$

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

where, σ → stefan's constant.

<u>Ques</u> A Body initially at 80°C cools to 64°C in 5 min. and 52°C in 10 min. What is Temp of Surrounding?

$T_1 = 80°C$ | $t = 5$ min
$T_2 = 64°C$ |

$$2.3026 \log_{10}\left[\frac{T_1 - T_0}{T_2 - T_0}\right] = K \times t$$

$$2.3026 \log_{10}\left[\frac{80 - T_0}{64 - T_0}\right] = K \times 5 \quad \text{--- (1)}$$

$T_1 = 64°C$, $T_2 = 52°C$, $t = 10 - 5 = 5$ min

$$2.3026 \log\left[\frac{64 - T_0}{52 - T_0}\right] = K \times 5$$

from eq^n no (1) & (2)

$$2.3026 \log\left[\frac{64 - T_0}{52 - T_0}\right] = 2.3026 \log\left[\frac{80 - T_0}{64 - T_0}\right]$$

$$\log_{10}\left[\frac{64 - T_0}{52 - T_0}\right] = \log_{10}\left[\frac{80 - T_0}{64 - T_0}\right]$$

Take Antilog

$$\frac{64 - T_0}{52 - T_0} = \frac{80 - T_0}{64 - T_0}$$

$$\boxed{T_0 = 16°C}$$

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Ques How much faster does a cup of coffee cool off from 100°C than 30°. Assume the coffee to act as a Black Body & Temp. of surrounding is 20°C?

Ans $T_1 = 100°C = 100 + 273 = 373\ K$
$T_2 = 30°C = 30 + 273 = 303\ K$
$T_3 = 20°C = 20 + 273 = 293\ K$

$$\frac{E_1}{E_2} = \left[\frac{T_1^4 - T_0^4}{T_2^4 - T_0^4}\right] = \frac{(373)^4 - (293)^4}{(303)^4 - (293)^4} \Rightarrow \frac{1198.68}{105.88}$$

$$\Rightarrow 11.3$$

$$E_1 = E_2 \times 11.3$$

Wien's Displacement Reaction

Wavelength of maximum Intensity of emission of Black Body radiation is inversely proportional to absolute Temp (T) of the Body.

$$\lambda m \propto \frac{1}{T}$$

$$\lambda m = \frac{b}{T}$$

[∵ b → wien's constant]

Qu1 The temp in body increased from 27°C to 127°C By what factor would be transmitted by increase its increase?

Qu2 Two stars radiate maximum energy at wavelength 3.6×10^{-7} & $4.8 \times 10^{-7} m$. What is ratio of their temp.

Ans2
$$\lambda_1 = 3.6 \times 10^{-7} m$$
$$\lambda_2 = 4.8 \times 10^{-7} m$$

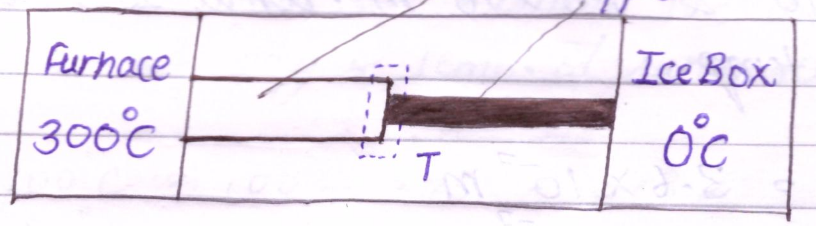
$$\lambda = \frac{b}{T} \Rightarrow \frac{\lambda_1}{\lambda_2} = \frac{T_2}{T_1} \Rightarrow \frac{T_2}{T_1} = \frac{3.6 \times 10^{-7} m}{4.8 \times 10^{-7} m}$$

$$\frac{T_2}{T_1} = \frac{3}{4} \Rightarrow \boxed{T_2 = \frac{3}{4} T_1}$$

Ans1
$$T_1 = 27^\circ C = 27 + 273 = 300 K$$
$$T_2 = 127^\circ C = 127 + 273 = 400 K$$

As we know
$$E = \sigma T^4$$
$$\frac{E_1}{E_2} = \frac{\sigma T_1^4}{\sigma T_2^4} \Rightarrow \left(\frac{300}{400}\right)^4 = \left(\frac{3}{4}\right)^4$$
$$\Rightarrow \frac{81}{256}$$

Qu3 What is Temp of Steel–Copper Junction in the steady state of system. Length of steel rod is 30 cm. Length of copper rod is 20 cm. Temp of furnace is 300°C. Temp of cold end is 0°C. The area of cross section of steal rod is twice that of copper rod & thermal conductivity of steel is $50.2 J sec^{-1} m^{-1} C^{\circ -1}$ & thermal conductivity of copper is 385 J sec^{-1} m^{-1} $°C^{-1}$



Diagram

Ans

$$\frac{\Delta Q}{\Delta t} = \frac{K \times A \times \Delta T}{l}$$

So,

$$\frac{K_S \times A_S \times (300 - T)}{l_S} = \frac{K_C \times A_C \times (T - 0)}{l_C}$$

$[\because A_S = 2A_C]$, $$\frac{50.2 \times 2A_C \times (300 - T)}{30} = \frac{385 \times A_C \times T}{20}$$

$$T = 44.50°C$$