THERMAL PROPERTIES OF MATTER

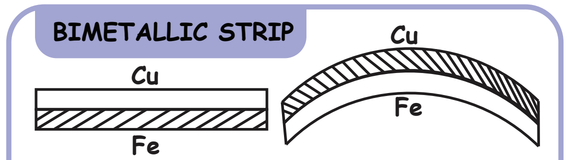
TEMPERATURE SCALE

$$\frac{C}{5}=\frac{F-32}{9}=\frac{K-273}{5}$$ (celcius-fahrenheit-kelvin conversion)

any scale conversion formula

$$\frac{\text{Reading on any scale} - \text{lower fixed point}}{\text{Upper fixed point} - \text{lower fixed point}} = \text{constant}$$

BIMETALLIC STRIP

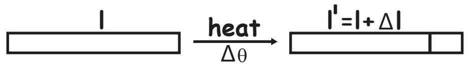


$\alpha_{cu} > \alpha_{Fe} \longrightarrow$ So when temperature increases

$\longrightarrow \Delta l$ of Cu $> \Delta l$ of Fe

$\longrightarrow$ strip with higher value of α will be on convex side

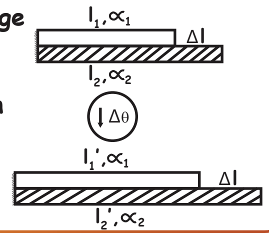
LINEAR THERMAL EXPANSION



1. $\Delta l = \alpha l \Delta\theta$
2. $l' = l(1+\alpha\Delta\theta)$
3. $\alpha = \frac{\Delta l}{l\Delta\theta} \longrightarrow$ unit $\longrightarrow$ /°c or/ k, dimension-K^{-1}

Whatever be the change in temperature, if the difference in length remains constant, then

$$l_1\alpha_1 = l_2\alpha_2$$



APPLICATIONS OF LINEAR EXPANSION

Pendulum clock

Fact $\longrightarrow$ When temperature increases, time period increases, clock runs slow

$\longrightarrow$ When temperature decreases, time period decreases, clock runs fast

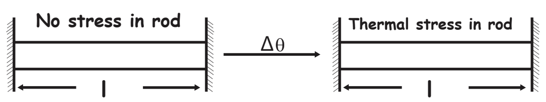
1) Loss of time in any given time interval t,

$$\Delta t = \frac{1}{2}\alpha\Delta\theta t$$

2) Time lost by clock in a day

$$\Delta t = \frac{1}{2}\alpha\Delta\theta t = \frac{1}{2}\alpha\Delta\theta 86400 = 43200\alpha\Delta\theta$$

Thermal Stress in a rigidly fixed rod



Thermal Stress=$Y\alpha\Delta\theta$

Thermal Force=$YA\alpha\Delta\theta$

Y-Young's Modulus

α-coefficent of linear expansion

Δθ -temperature change

A -Area of rod

ERROR IN SCALE READING DUE TO EXPANSION OR CONTRACTION

Result: At $\theta' > \theta$ True value > Scale reading

At $\theta' < \theta$ True value < Scale reading

$\boxed{\text{True value} = \text{Scale reading } (1+\alpha\Delta\theta)}$

EXPANSION OF CAVITY

Area of hole increases. Body expands on heating. Expansion of area of body is independent of shape and size of hole

SUPERFICIAL/AREAL EXPANSION

1. $\Delta A = A\beta\Delta\theta$ β -coefficient of areal expansion
2. $A' = A(1+\beta\Delta\theta)$
3. $\beta = \frac{\Delta A}{A\Delta T} \longrightarrow$ unit — /°c or/ k, dimension-$[K^{-1}]$
4. $\beta = 2\alpha$

CUBICAL EXPANSION/VOLUME EXPANSION

1. $\Delta V = V\gamma\Delta\theta$ γ = coefficient of volumetric expansion
2. $V' = V(1+\gamma\Delta\theta)$
3. $\gamma = \frac{\Delta V}{V\Delta\theta} \longrightarrow$ unit $\longrightarrow$ /°c or /K

k, dimension-$[K^{-1}]$ $\boxed{\alpha:\beta:\gamma = 1:2:3}$

4. $\gamma = 3\alpha$

Variation of density with temperature

Density $\propto \frac{1}{\text{Volume}}$

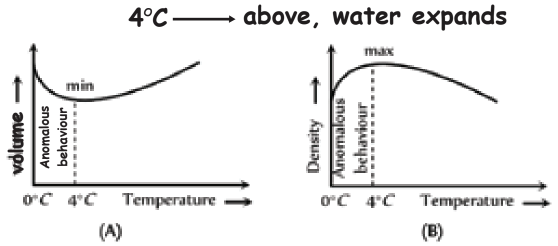
$V' = V(1+\gamma\Delta\theta)$

then $\rho' = \rho(1-\gamma\Delta\theta)$

ANOMALOUS EXPANSION OF WATER

1. Water has maximum density at 4°C (minimum volume)
2. On heating, 0°C ⟶ 4°C, water contracts

4°C ⟶ above, water expands



REAL AND APPARENT EXPANSION OF LIQUID

1. Apparent expansion of liquid ⟶ (Real expansion of liquid - expansion of solid in which liquid is contained)
2. Apparent change in volume

$\Delta V_{apparent} = V_0\gamma_{apparent}\Delta\theta$

$\Rightarrow \Delta V_{apparent} = V_0(\gamma_l - \gamma_s)\Delta\theta$

$\Rightarrow \Delta V_{apparent} = V_0(\gamma_l - 3\alpha_s)\Delta\theta$

$\Rightarrow \gamma_{apparent} = \gamma_l - 3\alpha_s$

γ_l -Real expansion of liquid

α_s -coefficent of linear expansion of solid

CALORIMETRY

$\boxed{1 \text{ calorie} = 4.2J}$

Heat Supplied (ΔQ)

- change in temperature of body
- change of state of body

1. $\Delta Q = ms\Delta T$

s-specific heat capacity

SI unit- $\frac{\text{Joule}}{\text{kg Kelvin}} \longrightarrow J\ kg^{-1}K^{-1}$

2. $s_{water} = 1\frac{cal}{g^oC} = 4.2\frac{J}{g^oC} = 4200\frac{J}{kg^oC}$

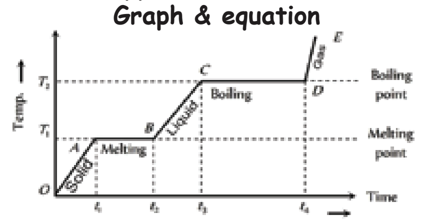
$s_{ice} = \frac{1}{2}\frac{cal}{g^oC} = 2.1\frac{J}{g^oC} = 2100\frac{J}{kg^oC}$

Melting: $\Delta Q = mL_f$, L_f-Latent heat of fusion

Boiling: $\Delta Q = mL_v$, L_v-Latent heat of vaporization

- $L_f = L_{ice} = 80\frac{cal}{g} = 80\times4.2\frac{J}{g} = 80\times4200\frac{J}{kg}$
- $L_v = L_{steam} = 540\frac{cal}{g} = 540\times4.2\frac{J}{g} = 540\times4200\frac{J}{kg}$

Heat supplied at constant rate Graph & equation



$$\frac{Q}{t} = \frac{msT_1}{t_1} = \frac{mL_f}{t_2-t_1} = \frac{ms(T_2-T_1)}{t_3-t_2} = \frac{mL_v}{t_4-t_3}$$

if specific heat is variable

$S = f(T)$ $T_1 \longrightarrow T_2$ $\Delta Q = \int_{T_1}^{T_2} msdT$

HEAT CAPACITY

Heat capacity=mass × specific heat capacity

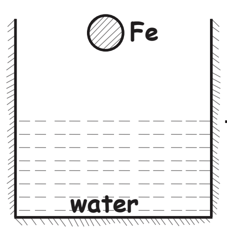
Unit= $\frac{cal}{^oC}$, SI unit is $\frac{J}{K}$

WATER EQUIVALENT

The mass of water that will absorb or lose the same quantity of heat as a given substance will do for same change in temperature

$m_w s_w = m_b s_b$ w=water, b=body

PRINCIPLE OF CALORIMETRY



Cu glass Vessel	Liquid	Hot iron sphere
m_1	m_2	m_3
s_1	s_2	s_3
T_1	T_2	T_3

Heat lost by the hotter bodies = Heat gained by colder bodies

$Q_3 = Q_1 + Q_2$

Final equilibrium temperature,

$$T_{eq} = \frac{m_1s_1T_1 + m_2s_2T_2 + m_3s_3T_3}{m_1s_1 + m_2s_2 + m_3s_3} = \frac{\Sigma msT}{\Sigma ms}$$

Facts : Calorimeter - A device for measurement of amount of heat involved in a process.

ICE-WATER SYSTEM

Problem solving methodology

1. m_1 gram ice $[-\theta_1\ ^oC]$ mixed with m_2 gram water$[\theta_2\ ^oC]$
2. Convert $-\theta_1\ ^oC$ ice ⟶ 0°C ice

$\Delta Q_1 = m_1 S_{ice}\theta_1$

3. Convert 0°C ice ⟶ 0°C water

$\Delta Q_2 = m_1 L_f$

4. Convert $\theta_2\ ^oC$ water ⟶ 0°C water

$\Delta Q_3 = m_2 S_{water}\theta_2$

check $\Delta Q_3 >=<$ or $\Delta Q_1 + \Delta Q_2$

$\Delta Q_3 > \Delta Q_1 + \Delta Q_2$

1. Whole ice melts into water
2. Additional heat $[\Delta Q' = \Delta Q_3 - (\Delta Q_1 + \Delta Q_2)]$ is used to increase the temperature of system from 0°C
3. Final temperature can be found out by

$\Delta Q' = M_{total} S_{water} T$

$\Delta Q_3 < \Delta Q_1 + \Delta Q_2$

1. Only m' g of ice melts
2. Mass of ice melted can be found by $m L_f = Q$ [m=mass of ice melted]
3. Final temperature is 0°C

CONVERSION OF MECHANICAL ENERGY TO HEAT ENERGY

1. Potential energy to heat energy

$\Delta U = mgh \xrightarrow{\text{converts to heat}} \Delta Q = m'L_f$ [m' = mass of substance melted/vaporized]

When equating, multiply ΔQ with 4200 J if L_f is in cal/g

i.e., $mgh = m'L_f \times 4200$

2. Kinetic energy to Heat energy

$K.E = \frac{1}{2}mv^2 \xrightarrow{\text{converts to heat}} \Delta Q = m'L_f$ [m' = mass of substance melted/vaporized]

If L_f is in $\frac{\text{calorie}}{g}$

then

$\frac{1}{2}mv^2 = m'L_f \times 4200$

HEAT TRANSFER

1. Conduction:

Heat flows from hot end to cold end.
Medium is necessary.
Slow process.

$$\frac{dQ}{dt} = KA\frac{d\theta}{dx}$$

Unit of 'K'= $\frac{\text{watt}}{\text{metre}^oC}$ or $\frac{\text{watt}}{\text{metre K}}$

'K' depends on the nature of material

$\frac{dQ}{dt}$ = Rate of flow of heat

A = Area of cross section

$\frac{d\theta}{dx}$ = Temperature gradient

K = coefficient of thermal conductivity

THERMAL PROPERTIES OF MATTER

OHM'S LAW OF CONDUCTION

Electrical Conduction

1) current, $I = \frac{dq}{dt}$

2) $I = \frac{\Delta V}{R}$ $(\Delta V = V_{high} - V_{low})$

3) electrical resistance, $R = \frac{\rho l}{A}$

4) $I = \frac{V_1 - V_2}{R} = \frac{(V_1 - V_2)A}{\rho l} = \frac{\sigma A}{l}(V_1 - V_2)$

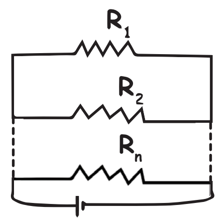
5) Combination of resistors

i) Series Combination

$R_{eq} = R_1 + R_2 + \ldots\ldots + R_n$

Here 'I' is same in all resistors

ii) Parallel Combination



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

Here $(V_1 - V_2)$ is same for all resistors

Thermal Conduction

1) Heat current, $H = \frac{dQ}{dt}$

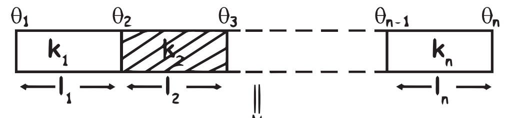
2) $H = \frac{\theta_1 - \theta_2}{R} = \frac{\Delta\theta}{R}$ $(\theta_1 > \theta_2)$

3) Thermal resistance, $R = \frac{l}{KA}$

4) $H = \frac{\theta_1 - \theta_2}{R} = \frac{\theta_1 - \theta_2}{(l/KA)} = \frac{KA}{l}(\theta_1 - \theta_2)$

5) Combination of conductors

i) Series Combination



replace to resistors

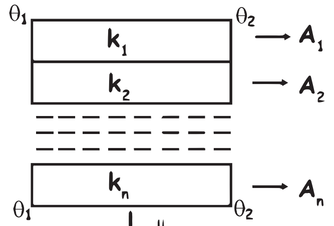
$R_1 = \frac{l_1}{K_1 A}$ $R_2 = \frac{l_2}{K_2 A}$

Find $R_{eq} = R_1 + R_2 + \ldots\ldots$

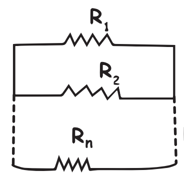
From that find 'K_{eq}'.

Here, heat current, H is same in a conductors

ii) Parallel Combination



replace with resistors



$R_1 = \frac{l}{K_1 A_1}$

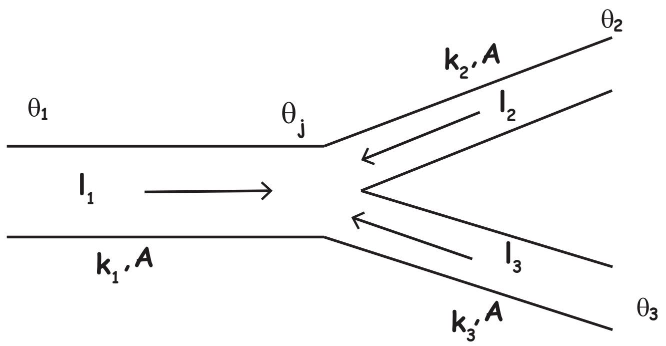
$R_2 = \frac{l}{K_2 A_2}$

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

from that find K_{eq}

Here, Temp Difference is same for all conductors

TEMPERATURE OF INTERMEDIATE JUNCTION



$I_1 + I_2 + I_3 = 0$

$\frac{\theta_1 - \theta_j}{R_1} + \frac{\theta_2 - \theta_j}{R_2} + \frac{\theta_3 - \theta_j}{R_3} = 0$

$$\theta_j = \frac{\frac{\theta_1}{R_1} + \frac{\theta_2}{R_2} + \frac{\theta_3}{R_3}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

CONVECTION

Requires a medium. Actual movement of fluid. Occus naturally or forced.

Natural convection takes place due to the effect of gravity

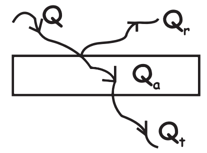
Applications:

Sea Breeze
Wind blows from sea to land during day time

Land Breeze
Wind blows from land to sea during night

RADIATION

Absorptive, reflective and Transmittive power



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

Absorptive power(a) $= \frac{Q_a}{Q} = \frac{\text{Energy absorbed}}{\text{Energy incident}}$

Reflective power(r) $= \frac{Q_r}{Q} = \frac{\text{Energy reflected}}{\text{Energy incident}}$

Transmittive power(t) $= \frac{Q_t}{Q} = \frac{\text{Energy transmitted}}{\text{Energy incident}}$

EMISSIVE POWER/INTENSITY OF THERMAL RADIATION

Emissive power(E) $= \frac{\text{Energy radiated}}{\text{area} \times \text{time}}$ unit $\longrightarrow \frac{\text{Watt}}{m^2}$

Spectral emissive power$(E_\lambda) = \frac{\text{Energy radiated}}{\text{area} \times \text{time} \times \text{wavelength}}$ unit $\rightarrow \frac{\text{Watt}}{m^3}$

Relation between E & $E_\lambda \Longrightarrow E = \int_0^\infty E_\lambda \, d\lambda$

EMISSIVITY (e)

$e = \frac{\text{Energy radiated by a general body}}{\text{Energy radiated by a black body}}$

value of e $\Longrightarrow 0 < e < 1$

If e=0 , the body radiates no energy

If e=1 , the body is a perfect black body

KIRCHHOFF'S LAW

Ratio of emissive power to absorptive power is same for all surfaces at the same temperature and is equal to the emissive power of a perfectly black body at that temperature.

$\frac{E_1}{a_1} = \frac{E_2}{a_2} = \ldots\ldots\ldots = E_b$

STEFAN'S LAW

Emissive power of a black body $\propto$ fourth power of absolute temperature and surface area of the body

$\boxed{E = \sigma A T^4}$ OR $\boxed{\frac{\Delta Q}{\Delta t} = \sigma A T^4}$

$\sigma \longrightarrow$ Stefan's constant

$\frac{\Delta Q}{\Delta t} \longrightarrow$ Radiant power

value of $\sigma \longrightarrow 5.67 \times 10^{-8}$ W $m^{-2} K^{-4}$

Dimension $\longrightarrow [\sigma] = MT^{-3}K^{-4}$

For ordinary body $E = e\sigma T^4$

$\frac{\Delta Q}{\Delta t} = eA\sigma T^4$ e=emissivity

In the presence of a surrounding.
(T_0=Surrounding temperature)
For black body,

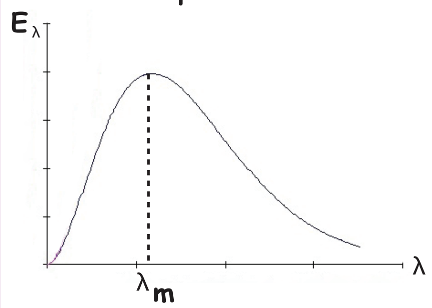
$E = \sigma A(T^4 - T_0^4)$

In the presence of a surrounding.
(T_0=Surrounding temperature)
For general body,

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

WIEN'S LAW

Wien's displacement law



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

$\lambda_m T = b$

b=Wien's constant

$\lambda_{m_1} T_1 = \lambda_{m_2} T_2$

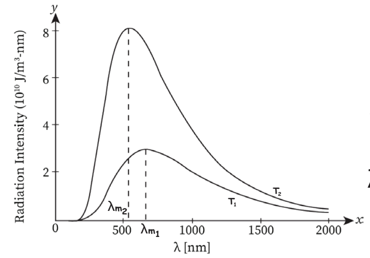
Area under the graph, $A = \int_0^\infty E_\lambda \, d\lambda = E = \sigma T^4$

Hence $\frac{A_1}{A_2} = \left[\frac{T_1}{T_2}\right]^4$

$b = 2.89 \quad 10^{-3}$ mK

[Dimensions]=[b]=[LK]

"As the temperature of the body increases, the wavelength at which the spectral intensity (E_λ) is maximum shift towards left."



$T_1 < T_2$

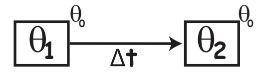
$\lambda_{m_1} > \lambda_{m_2}$

NEWTON'S LAW OF COOLING

EQUATION FOR PROBLEM SOLVING

if $\theta_1 - \theta_2$ is small, then

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



$\theta_1 > \theta_2$

Δt=time

$\theta_0 \rightarrow$ surrounding temperature

NEWTON'S LAW OF COOLING

Rate of cooling $\propto$ excess temperature of the body over the surrounding.

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

T=Temperature of body
T_0=Temperature of surrounding
T_i = initial temperature of the body

$\frac{T - T_0}{T_i - T_0} = e^{-kt}$