# PHYSICS

## NEET and JEE Main 2020 : 45 Days Crash Course

# Calorimetry, Thermal Expansion and Heat Transfer

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# Heat

The energy that is being transferred between two bodies or between adjacent parts of a body as a result of temperature difference is called heat. Thus, heat is a form of energy. It is energy in transit whenever temperature differences exist.

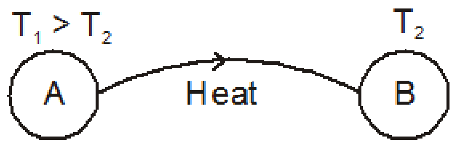
Once it is transferred, it becomes the internal energy of the receiving body. It should be clearly understood that the word "heat" is meaningful only as long as the energy is being transferred.

Thus, expressions like "heat in a body" or "heat of a body" are meaningless.

S.I. unit of heat energy is joule (J). Another common unit of heat energy is calorie (cal).

**1 calorie = 4.18 joules.**

**1 calorie :** The amount of heat needed to increase the temperature of 1 gm of water from 14.5 to 15.5 °C at one atmospheric pressure is 1 calorie.



# Specific Heat

Specific heat of substance is equal to heat gain or released by that substance to raise or fall its temperature by 1° C for a unit mass of substance.

$$s = \frac{Q}{m\Delta T}$$

$$\boxed{\Delta Q = m\, s\, \Delta T}$$

**Specific heat of water :** S = 4200 J/kg°C = 1000 cal/kg°C = 1 Kcal/kg°C = $\boxed{\text{1 cal/gm°C}}$

**Specific heat of steam = specific heat of ice = half of specific heat of water** = 0.5 cal/gm°C

1kg T → 20°C to 80°C

$\Delta Q = m s \Delta T = 1000 \times 1 \times 60$

$= 60$ Kcal

# Example

Find amount of heat required to increase~~s~~ the temperature of 1 kg water by 20° C

Sol.

Temp.

Heat required = $\Delta Q = ms\Delta\theta$

$\because \quad s = 1$ cal/gm°C = 1 Kcal/kg°C

$\Delta Q = 1 \times 20 = 20$ Kcal.

# Heat Capacity or Thermal Capacity

Heat capacity of a body is defined as the amount of heat required to raise the temperature of that body by 1°.

If 'm' is the mass and 's' the specific heat of the body, then
**Heat capacity = m s**.
Units of heat capacity in: CGS system is, **cal °C$^{-1}$**; SI unit is **JK$^{-1}$**

$$\boxed{C = ms}$$

$$C = \frac{\Delta Q}{\Delta T}$$

$$s = \frac{\Delta Q}{m \Delta T}$$

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

$$\Delta Q = \int m s \, dT$$

variable

# Phase Change and Latent Heat

T const  Hidden

Heat required for the change of phase or state,
$\boxed{Q = mL}$,  L = latent heat.

**Latent heat (L):** The heat supplied to a substance which changes its state at constant temperature is called latent heat of the body.

**Latent heat of Fusion ($L_f$):** The heat supplied to a substance which changes it from solid to liquid state at its melting point and 1 atm. pressure is called latent heat of fusion. Latent heat of fusion of ice is 80 kcal/kg   80 cal/gm

**Latent heat of vaporization ($L_v$):** The heat supplied to a substance which changes it from liquid to vapour state at its boiling point and 1 atm. pressure is called latent heat of vaporization. Latent heat of vaporization of water is 540 kcal $kg^{-1}$.   540 cal/gm

**Latent heat of ice :** L = 80 cal/gm = 80 Kcal/kg = 4200 × 80 J/kg

**Latent heat of steam :** L = 540 cal/gm = 540 Kcal/kg = 4200 × 540 J/kg

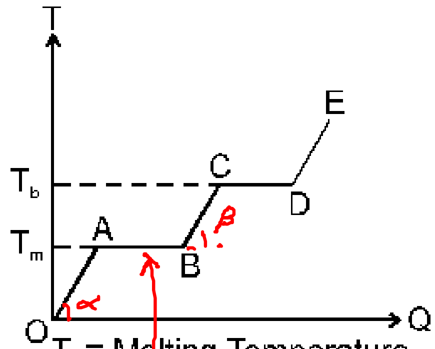
# Graph of Phase Change

The given figure, represents the change of state by different lines

OA – solid state , AB – solid + liquid state (Phase change)

BC – liquid state , CD – liquid + vapour state (Phase change)

DE – vapour state




$T_b$ = Melting Temperature

$T_m$ = Boiling Temperature

$\Delta Q = ms\Delta T$

$\Delta T = \frac{1}{ms}\Delta Q$

$y = (m)x$

Slope $\propto \frac{1}{ms}$

$m$ = same

Slope $\propto \frac{1}{s}$

length $\propto L$

# Calorimetry

The branch of thermodynamics which deals with the measurement of heat is called calorimetry.

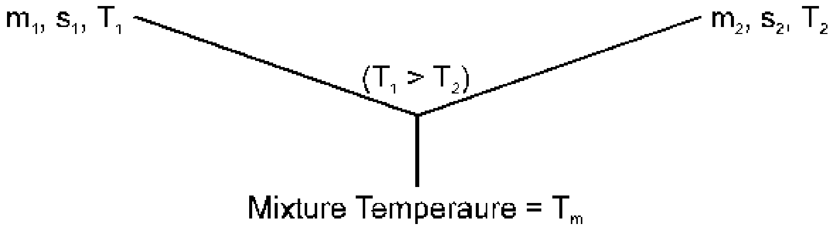
**Law of Mixture**

When two substances at different temperatures are mixed together, then exchange of heat continues to take place till their temperatures become equal. This temperature is then called final temperature of mixture. Here,

**Heat taken by one substance = Heat given by another substance**

$$\Rightarrow \quad m_1 s_1 (T_1 - T_m) = m_2 s_2 (T_m - T_2)$$

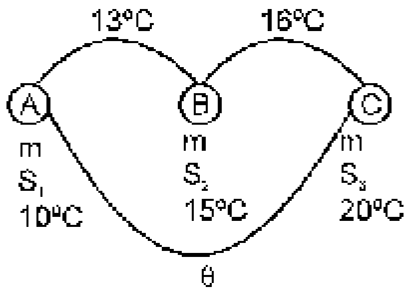
$$\boxed{T_m = \frac{m_1 s_1 T_1 + m_2 s_2 T_2}{m_1 s_1 + m_2 s_2}}$$



# Example

The temperature of equal masses of three different liquids A, B, and C are 10ºC 15ºC and 20ºC respectively. The temperature when A and B are mixed is 13ºC and when B and C are mixed, it is 16ºC. What will be the temperature when A and C are mixed?

Sol.




when A and B are mixed

$mS_1 \times (13 - 10) = m \times S_2 \times (15 - 13)$

$3S_1 = 2S_2$ .....(1)

when B and C are mixed

$S_2 \times 1 = S_3 \times 4$ ......(2)

when C and A are mixed

$S_1(\theta - 10) = S_3 \times (20 - \theta)$ ....(3)

by using equation (1), (2) and (3)

we get $\theta = \dfrac{140}{11}$ °C

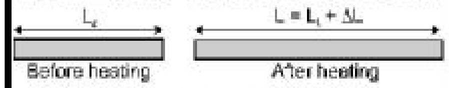
# Thermal Expansion

Most materials expand when their temperature is increased.
Thermal expansion is like a photographic enlargement

$T \uparrow$

$r \uparrow R \uparrow t \uparrow$


### LINEAR EXPANSION




Change in length

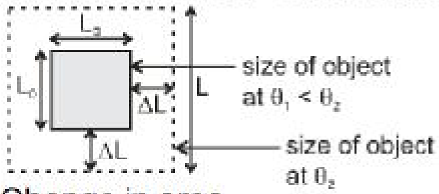
$\Delta L = \alpha L_0 \Delta T$ coeff. of linear exp.

Final Length

$L = L_0 (1 + \alpha \Delta T)$

↳ $L_0 + \Delta L$

### SUPERFICIAL OR AREAL EXPANSION




Change in area

$\Delta A = \beta A_0 \Delta T$ coeff. of areal exp.

Final area

$A = A_0 (1 + \beta \Delta T)$

### VOLUME OR CUBICAL EXPANSION

Change in volume

$\Delta V = \gamma V_0 \Delta T$

Final volume

$V = V_0 (1 + \gamma \Delta T)$

coeff. of vol. exp.

### RELATION BETWEEN $\alpha$ , $\beta$ AND $\gamma$

$\beta = 2\alpha$ ; $\gamma = 3\alpha$

(i) For isotropic solids: $\alpha : \beta : \gamma = 1 : 2 : 3$ or $\frac{\alpha}{1} = \frac{\beta}{2} = \frac{\gamma}{3}$

(ii) For non-isotropic solid $\beta = \alpha_1 + \alpha_2$ and $\gamma = \alpha_1 + \alpha_2 + \alpha_3$. Here $\alpha_1$, $\alpha_2$ and $\alpha_3$ are coefficient of linear expansion in X, Y and Z direction.

# Example

What is the percentage change in length of 1m iron rod if its temperature changes by 100ºC. $\alpha$ for iron is $2 \times 10^{-5}$/ºC.

Sol.

Percentage change in length due to temperature change

$$\%\ell = \frac{\Delta\ell}{\ell} \times 100 = \alpha\Delta\theta \times 100$$

$$= 2 \times 10^{-5} \times 100 \times 100$$

$$= 0.2\%$$ **Ans.**

$\Delta l = \alpha l \Delta\theta$

$\frac{\Delta l}{l} = \alpha\Delta\theta$

fractional

percentage $\rightarrow \frac{\Delta l}{l} \times 100$

# Variation of Time Period of Pendulum Clocks

$T = 2\pi\sqrt{\frac{L}{g}}$ at temperature $\theta$.

For small percentage change in L

$$\frac{\Delta T}{T} = \frac{1}{2}\frac{\Delta L}{L} = \frac{1}{2}\alpha\,\Delta\,\theta$$

Gain or loss in time in duration of 't' in

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

If T is the correct time then

(a) $\theta < \theta_0$ , $T' < T$ clock becomes fast and gain time

(b) $\theta > \theta_0$ , $T' > T$ clock becomes slow and loose time

$$f = \frac{x^a y^b}{z^c}$$

For small percentage changes

$$\frac{\Delta f}{f} = a\frac{\Delta x}{x} + b\frac{\Delta y}{y} - c\frac{\Delta z}{z}$$

# Example

A plane lamina has area $2m^2$ at 10°C then what is its area at 110°C It's superficial expansion is $2 \times 10^{-5}/°C$

Sol.

$$A = A_0 \; (1 + \beta \, \Delta \, \theta)$$
$$= 2 \{ 1 + 2 \times 10^{-5} \times (110 - 10) \}$$
$$= 2 \times \{1 + 2 \times 10^{-3}\} \quad \textbf{Ans.}$$

$= 2 \times 1.002$

$= 2.004 \; m^2$

# Variation of Density with Temperature

As we known that mass = volume × density .

Mass of substance does not change with change in temperature so with increase of temperature, volume increases so density decreases and vice-versa.

$$\boxed{d = \frac{d_0}{(1+\gamma\Delta T)}}.$$

For solids values of $\gamma$ are generally small so we can write $\boxed{d = d_0\,(1-\gamma\,\Delta T)}$ (using binomial expansion).

$d_0 = \frac{m}{V_0}$

$d' = \frac{m}{V'} = \frac{m}{V_0(1+\gamma\Delta T)} = \frac{d_0}{1+\gamma\Delta T}$

$= d_0(1+\gamma\Delta T)^{-1}$

$\gamma\Delta T << 1$

$d' = d_0(1-\gamma\Delta T)$

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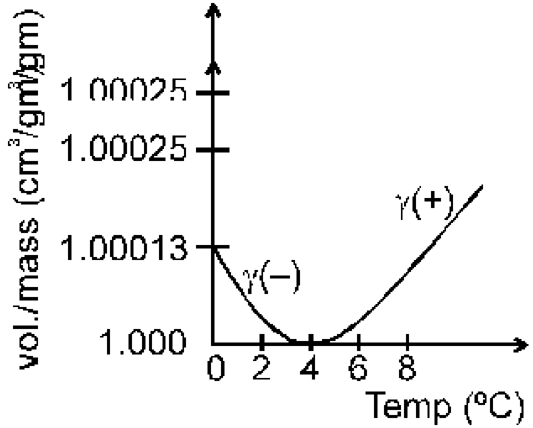
# Anomalous Expansion of water

For water density increases from 0 °C to 4 °C so $\gamma$ is negative and for 4 °C to higher temperature $\gamma$ is positive.

At 4 °C density is maximum.

This anamolous behaviour of water is due to presence of three types of molecules i.e. $H_2O$, $(H_2O)_2$ and $(H_2O)_3$ having different volume/mass at different temperatures.



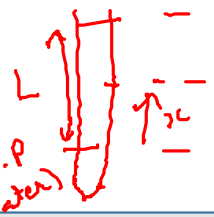

$0 \rightarrow 4°C$ $\qquad$ $4°C \rightarrow 100°C$

$V\downarrow \; d\uparrow$ $\qquad$ $V\uparrow \; d\downarrow$

# Comparison between Different Temperature Scales

$$\frac{K-273}{100} = \frac{C}{100} = \frac{F-32}{180} = \frac{N-LSP}{USP-LSP}$$

| | Kelvin | Celsius | Fahrenheit | New Scale |
|---|---|---|---|---|
| (water-steam) U.S.P | 373 | 100 | 212 | U.S.P |
| | K | C | F | N |
| L.S.P (ice-water) | 273 | 0 | 32 | L.S.P |




$$\frac{x}{L} = \text{const}$$

# Example

The upper and lower fixed points of a faulty thermometer are 5°C and 105° C .If the thermometer reads 25° C , what is the actual temperature ?

L.S.P    U.S.P

Sol.

$$\frac{25-5}{100} = \frac{C-0}{100}$$

$$C = 20^\circ C$$

$$\frac{N - L.S.P.}{U.S.P - L.S.P} = \frac{C}{100}$$

# Heat Transfer

Heat is energy in transit which flows due to temperature difference; from a body at higher temperature to a body at lower temperature. This transfer of heat from one body to the other takes place through three routes.

(i) Conduction → medium req. , no actual movement of particles

(ii) Convection → " , particles transfer

(iii) Radiation → medium not req.

# Conduction

The process of transmission of heat energy in which heat is transferred from one particle of the medium to the other, but each particle of the medium stays at its own position is called conduction.

Consider a slab of face area A, Lateral thickness L, whose faces have temperatures $T_H$ and $T_C$ ($T_H > T_C$).

The amount of heat crossing the area A of the slab at position x in time t is given by

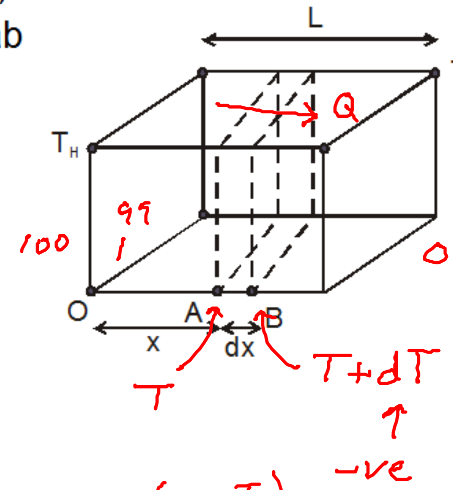
$$\boxed{\frac{dQ}{dt} = -KA\frac{dT}{dx}}$$

$T_c - T_H$

K = thermal conductivity of the material,

$\left(\frac{dT}{dx}\right)$ = temperature gradient

The (–) sign shows heat flows from high to low temperature ($\Delta T$ is a –ve quantity)

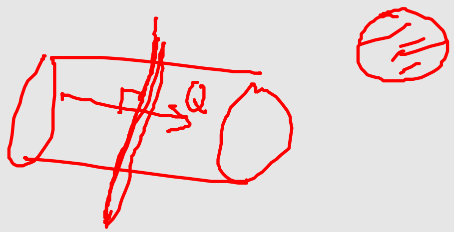



At steady state

Power $\rightarrow$ $$\frac{Q}{t} = KA\left(\frac{T_H - T_C}{L}\right)$$

$$P = \frac{dQ}{dt} = KA\left(\frac{T_2 - T_1}{L}\right)$$

$T_2 > T_1$



# Thermal Resistance to Conduction

For a slab of cross-section A, Lateral thickness L and thermal conductivity K,

Thermal resistance, $R = \frac{L}{KA}$

In terms of R, the amount of heat flowing though a slab in steady-state (in time t)

$$\frac{Q}{t} = \frac{(T_H - T_C)}{R}$$

If we name $\frac{Q}{t}$ as thermal current $i_T$

then, $i_T = \frac{T_H - T_C}{R}$

This is mathematically equivalent to OHM's law, with temperature playing the role of electric potential. Hence results derived from OHM's law are also valid for thermal conduction.

$$I = \frac{V_1 - V_2}{R}$$

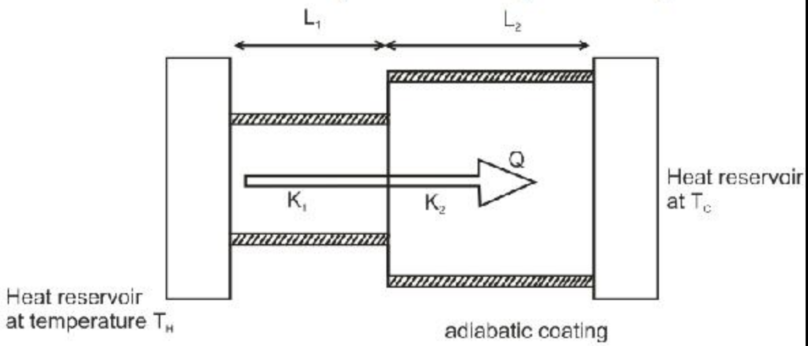
$$R = \frac{\rho L}{A} = \frac{1}{\sigma} \frac{L}{A}$$

Thermal current $\rightarrow$ $\frac{dQ}{dt} = \frac{KA(T_H - T_C)}{L}$

$$\frac{L}{KA} = R$$

# Slabs in Parallel and Series

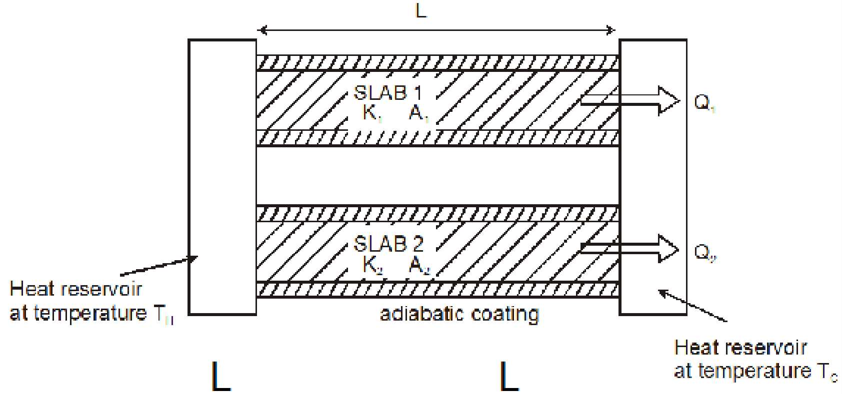
## Slabs in series (in steady state)




$$R_1 = \frac{L_1}{K_1A_1}, \qquad R_2 = \frac{L_2}{K_2A_2}$$

$$i = \frac{T_H - T_C}{R} \qquad R = R_1 + R_2 + R_3 + \ldots\ldots$$

## Slabs in parallel (in steady state)




$$R_1 = \frac{L}{K_1A_1}, \qquad R_2 = \frac{L}{K_2A_2}$$

$$i = \frac{T_H - T_C}{R_{eq}}, \qquad \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

# Convection

When heat is transferred from one point to the other through actual movement of heated particles, the process of heat transfer is called convection. In liquids and gases, some heat may be transported through conduction. But most of the transfer of heat in them occurs through the process of convection. Convection occurs through the aid of earth's gravity.