Actually no body is perfectly rigid and every body can be deformed more or less by the application of suitable forces. All these deformed bodies however regain their original shape or size, when the deforming forces are removed.

The property of matter by virtue of which a body tends to regain its original shape and size after the removal of deforming forces is called elasticity.

SOME TERMS RELATED TO ELASTICITY:

• Deforming Force

External force which try to change in the length, volume or shape of the body is called deforming force.

• Perfectly Elastic Body

The body which perfectly regains its original form on removing the external deforming force, is defined as a perfectly elastic body. Ex. : quartz – Very nearly a perfect elastic body.

Plastic Body

- (a) The body which does not have the property of opposing the deforming force, is known as a plastic body.
- (b) The bodies which remain in deformed state even after removed of the deforming force are defined as plastic bodies.

• Internal restoring force

When a external force acts at any substance then due to the intermolecular force there is a internal resistance produced into the substance called internal restoring force.

At equilibrium the numerical value of internal restoring force is equal to the external force.

STRESS

The internal restoring force acting per unit area of cross-section of the deformed body is called stress.

$$Stress = \frac{Internal \ restoring \ force}{Area \ of \ cross \ section} \quad = \quad \frac{F_{int \ ernal}}{A} = \frac{F_{external}}{A}$$

Stress depends on direction of force as well as direction of area of application so it is tensor.

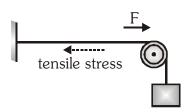
SI UNIT: N-m⁻² Dimensions: M¹ L⁻¹ T⁻²

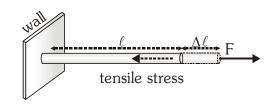
There are three types of stress:-

• Longitudinal Stress

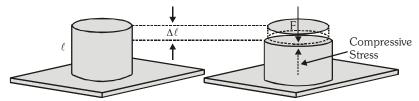
When the stress is normal to the surface of body, then it is known as longitudinal stress. There are two types of longitudinal stress

(a) **Tensile Stress:** The longitudinal stress, produced due to increase in length of a body, is defined as tensile stress.





(b) Compressive Stress: The longitudinal stress, produced due to decrease in length of a body, is defined as compressive stress.

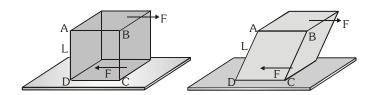


(c) Volume Stress

If equal normal forces are applied every one surface of a body, then it undergoes change in volume. The force opposing this change in volume per unit area is defined as volume stress.

(d) Tangential Stress or Shear Stress

When the stress is tangential or parallel to the surface of a body then it is known as shear stress. Due to this stress, the shape of the body changes or it gets twisted.



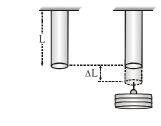
STRAIN

• The ratio of change of any dimension to its original dimension is called strain.

$$Strain = \frac{change in size of the body}{original size of the body}$$

- It is a unitless and dimensionless quantity.
- There are three types of strain: Type of strain depends upon the directions of applied force.

• Longitudinal strain =
$$\frac{\text{change in length of the body}}{\text{initial length of the body}} = \frac{\Delta L}{L}$$

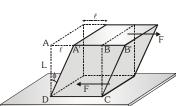


• **Volume strain**=
$$\frac{\text{change in volume of the body}}{\text{original volume of the body}} = \frac{\Delta V}{V}$$

• Shear strain

When a deforming force is applied to a body parallel to its surface then its shape (not size) changes. The strain produced in this way is known as shear strain. The strain produced due to change of shape of the body is known as shear strain.

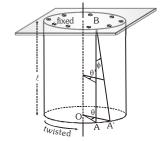
$$tan \ \phi = \frac{\ell}{L} \ or \quad \phi = \frac{\ell}{L} = \frac{displacement \ of \ upper \ face}{distance \ between \ two \ faces}$$



ALLEN

Relation Between angle of twist and Angle of shear

When a cylinder of length ' ℓ ' and radius 'r' is fixed at one end and and tangential force is applied at the other end, then the cylinder gets twisted. Figure shows the angle of shear ABA' and angle of twist AOA'. Arc AA' = r θ and Arc AA' = $\ell \phi$ so $r\theta = \ell \phi$



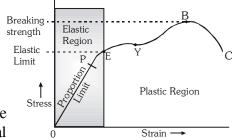
$$\Rightarrow \phi = \frac{r\theta}{\ell}$$

where θ = angle of twist, ϕ = angle of shear

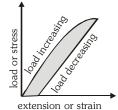
- When a material is under tensile stress restoring force are caused by intermolecular attraction while undercompressive stress, the restoring force are due to intermolecular repulsion.
- If the deforming force is inclined to the surface at an angle θ such that $\theta \neq 0$ and $\theta \neq 90^{\circ}$ then both tangential and normal stress are developed.
- Linear strain in the direction of force is called **longitudinal** strain while in a direction perpendicular to force **lateral strain**.

STRESS - STRAIN GRAPH

• **Proportion Limit**: The limit in which Hook's law is valid and stress is directly proportional to strain is called proportion limit. Stress ∝ Strain



- **Elastic limit:** That maximum stress which on removing the deforming force makes the body to recover completely its original state.
- **Yield Point:** The point beyond elastic limit, at which the length of wire starts increasing without increasing stress, is defined as the yield point.
- **Breaking Point:** The position when the strain becomes so large that the wire breaks down at last, is called breaking point. At this position the stress acting in that wire is called breaking stress and strain is called breaking strain.
- Elastic after effect or Elastic Relaxation time: The Property, by virtue of which a body does not regain its original form immediately after removing the deforming force but gains it after some time, is define as elastic relaxation time.
- Elastic Fatigue: When the deforming force, applied on a body, is changed rapidly then it temporarily loses its property of elasticity. This is known as elastic fatigue.
- Creep: If a small force is applied for a long time then it causes breaking of metal. For example A fan is hung for 200 years then the shaft will break.
- Elastic Hysteresis: The strain persists even when the stress is removed. This lagging behind of strain is called elastic hysteresis. This is the reason why the values of strain for same stress are different while increasing the load and while decreasing the load.

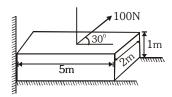


• **Breaking Stress :** The stress required to cause actual facture of a material is called the breaking stress Breaking stress = F/A

- Breaking stress also measures the tensile strength.
- Metals with small plastic deformation are called brittle.
- Metals with large plastic deformation are called ductile.
- Elasticity restoring forces are strictly conservative only when the elastic hysteresis is zero. i.e. the loading and unloading stress strain curves are identical.
- The material which have low elastic hysteresis have also low elastic relaxation time.
- Ex. Find out longitudinal stress and tangential stress on a fixed block.

Sol. Longitudinal or normal stress
$$\sigma_1 = \frac{100 \sin 30^{\circ}}{5 \times 2} = 5 \text{ N/m}^2$$

Tangential stress
$$\sigma_2 = \frac{100\cos 30^{\circ}}{5 \times 2} = 5\sqrt{3} \text{N/m}^2$$



Ex. The breaking stress of aluminium is 7.5×10^8 dyne cm⁻². Find the greatest length of aluminium wire that can hang vertically without breaking. Density of aluminium is 2.7 g cm^{-3} . Given : $g = 980 \text{ cm s}^{-2}$.

Sol. Let ℓ be the greatest length of the wire that can hang vertically without breaking. Mass of wire m = cross-sectional area $(A) \times length$ $(\ell) \times density$ (ρ) , Weight of wire $= mg = A\ell\rho g$ This is equal to the maximum force that the wire can withstand.

∴ Breaking stress =
$$\frac{\ell A \rho g}{A} = \ell \rho g \Rightarrow 7.5 \times 10^8 = \ell \times 2.7 \times 980$$

$$\Rightarrow$$
 $\ell = \frac{7.5 \times 10^8}{2.7 \times 980} \text{ cm} = 2.834 \times 10^5 \text{cm} = 2.834 \text{ km}$

HOOKE'S LAW

If the deformation is small, the stress in a body is proportional to the corresponding strain, this fact

is known as Hooke's Law. Within elastic limit: stress \propto strain $\Rightarrow \frac{\text{stress}}{\text{strain}} = \text{constant}$

This constant is known as modulus of elasticity or coefficient of elasticity.

The modulus of elasticity depends only on the type of material used. It does not depend upon the value of stress and strain.

YOUNG'S MODULUS OF ELASTICITY 'Y'

- Within elastic limit the ratio of longitudinal stress and longitudinal strain is called Young's modulus of elasticity.
- $\bullet \qquad Y \, = \, \frac{\text{longitudinal stress}}{\text{longitudinal strain}} = \, \frac{F \, / \, A}{\ell \, / \, L} = \, \frac{F \, L}{\ell \, A}$
- Within elastic limit the force acting upon a unit area of a wire by which the length of a wire becomes double, is equivalent to the Young's modulus of elasticity of material of a wire.
- If L is the length of wire, r is radius and ℓ is the increase in length of the wire by suspending a

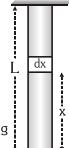
weight Mg at its one end then Young's modulus of elasticity of the material of wire $Y = \frac{\left(Mg / \pi r^2\right)}{\left(\ell / L\right)} = \frac{MgL}{\pi r^2 \ell}$.

• Unit of Y : N/m^2 • Dimensions of Y : $M^1L^{-1}T^{-2}$

ALLEN

Increment of length due to own weight

Let a rope of mass M and length L is hanged vertically. As the tension of different point on the rope is different. Stress as well as strain will be different at different point.



(i) maximum stress at hanging point (ii) minimum stress at lower point

Consider a dx element of rope at x distance from lower end then tension $T = \left(\frac{M}{L}\right) \times g$

So stress =
$$\frac{T}{A} = \left(\frac{M}{L}\right) \frac{xg}{A}$$

Let increase in length of dx is dy then strain = $\frac{dy}{dx}$

So Young modulus of elasticity
$$Y = \frac{\text{stress}}{\text{strain}} = \frac{\frac{M}{L} \frac{xg}{A}}{\frac{dy}{dx}} \Rightarrow \left(\frac{M}{L}\right) \frac{xg}{A} dx = Y dy$$

For full length of rope
$$\frac{\text{Mg}}{\text{LA}}\int_0^L x dx = Y \int_0^{\Delta \ell} dy \Rightarrow \frac{\text{Mg}}{\text{LA}} \frac{L^2}{2} = Y \Delta \ell \Rightarrow \Delta \ell = \frac{\text{MgL}}{2\text{AY}}$$

[Since the stress is varying linearly we may apply average method to evaluate strain.]

BULK MODULUS OF ELASTICITY 'K' or 'B'

• Within elastic limit the ratio of the volume stress and the volume strain is called bulk modulus of elasticity.

• K or B =
$$\frac{\text{volume stress}}{\text{volume strain}} = \frac{F/A}{\frac{-\Delta V}{V}} = \frac{\Delta P}{\frac{-\Delta V}{V}}$$

The minus sign indicates a decrease in volume with an increase in stress.

- Unit of K: N m⁻² or pascal
- Bulk modulus of an ideal gas is process dependence.
 - For isothermal process $PV = constant \Rightarrow PdV + VdP = 0 \Rightarrow P = \frac{-dP}{dV/V}$ So bulk modulus = P
 - For adiabatic process $PV^{\gamma} = \text{constant} \Rightarrow \gamma PV^{\gamma-1} dV + V^{\gamma} dP = 0$

$$\Rightarrow \gamma P dV + V dP = 0 \Rightarrow \gamma P = \frac{-dP}{dV/V}$$
 So bulk modulus = γP

• For any polytropic process PVⁿ = constant

$$\Rightarrow nPV^{n-1}dV + V^ndP = 0 \Rightarrow PdV + VdP = 0 \Rightarrow nP = \frac{-dP}{dV/V}$$
 So bulk modulus = nP

• Compressibility: The reciprocal of bulk modulus of elasticity is defined as compressibility. $C = \frac{1}{K}$

MODULUS OF RIGIDITY 'n'

• Within elastic limit the ratio of shearing stress and shearing strain is called modulus of rigidity of a material.

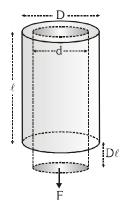
$$\bullet \qquad \eta = \frac{\text{shearing stress}}{\text{Shearing strain}} \ = \left(\frac{F_{\text{tan gential}}}{A}\right) \ = \ \frac{F_{\text{tan gential}}}{A\phi}$$

Note: Angle of shear '\phi' always taking in radian

Poisson's Ratio (σ)

In elastic limit, the ratio of lateral strain and longitudinal strain is called Poisson's ratio.

$$\sigma = \frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{\beta}{\alpha} \; ; \; \; \beta = \frac{-\Delta D}{D} = \frac{d - D}{D} \; \; \& \; \; \alpha = \frac{\Delta L}{L}$$



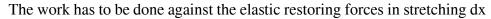
WORK DONE IN STRETCHING A WIRE

(POTENTIAL ENERGY OF A STRETCHED WIRE)

When a wire is stretched, work is done against the interatomic forces, which is stored in the form of elastic potential energy.

For a wire of length L₀ stretched by a distance x, the restoring elastic force is :

$$F = stress \times area = Y \left[\frac{x}{L_{\circ}} \right] A$$

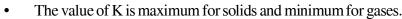


$$dW = F dx = \frac{YA}{L_0} x dx$$

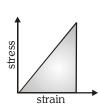
The total work done in stretching the wire from x = 0 to $x = \Delta \ell$ is, then

$$W = \int\limits_0^{\Delta\ell} \frac{YA}{L_o} x dx = \frac{YA}{L_o} \left[\frac{x^2}{2} \right]_0^{\Delta\ell} \ = \ \frac{YA(\Delta\ell)^2}{2L_o}$$

$$W = \frac{1}{2} \times Y \times (strain)^2 \times original \ volume = \frac{1}{2} (stress) \ (strain) \ (volume)$$



- For any ideal rigid body all three elastic modulus are infinite.
- η is the characteristic of solid material only as the fluids do not have fixed shape.
- Potential energy density = area under the stress–strain curve.
- Young's modulus = Slope of the stress–strain curve

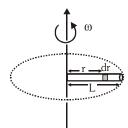


Ex. A steel wire of 4.0 m in length is stretched through 2.00 mm. The cross–sectional area of the wire is 2.0 mm^2 . If Young's modulus of steel is $2.0 \times 10^{11} \text{ N/m}^2$ find (i) the energy density of wire (ii) the elastic potential energy stored in the wire.

Sol. (i) The energy density of stretched wire $=\frac{1}{2} \times \text{stress} \times \text{strain} = \frac{1}{2} \times \text{Y} \times (\text{strain})^2$

=
$$\frac{1}{2} \times 2.0 \times 10^{11} \times \left[\frac{2 \times 10^{-3}}{4} \right]^2 = 2.5 \times 10^4 \text{ J/m}^3$$

- (ii) Elastic potential energy = energy density × volume = $2.5 \times 10^4 \times (2.0 \times 10^{-6}) \times 4.0 \text{ J}$ = $20 \times 10^{-2} = 0.20 \text{J}$
- Ex. A thin uniform metallic rod of length 0.5 m and radius 0.1 m rotates with an angular velocity 400 rad/s in a horizontal plane about a vertical axis passing through one of its ends. Calculate (a) tension in the rod and (b) the elongation of the rod. The density of material of the rod is 10^4 kg/m³ and the Young's modulus is 2×10^{11} N/m².
- **Sol.** (a) Consider an element of length dr at a distance r from the axis of rotation as shown in figure. The centripetal force acting on this element will be $dT = dmr\omega^2 = (\rho Adr)r\omega^2$. As this force is provided by tension in the rod (due to elasticity), so the tension in the rod at a distance r from the axis of rotation will be due to the centripetal force due to all elements between x = r to x = L



i.e.,
$$T = \int_{r}^{L} \rho A \omega^{2} r dr = \frac{1}{2} \rho A \omega^{2} \left[L^{2} - r^{2}\right] ...(i)$$

So here
$$T = \frac{1}{2} \times 10^4 \times \pi \times 10^{-2} \times (400)^2 \left[\left(\frac{1}{2} \right)^2 - r^2 \right] = 8\pi \times 10^6 \left[\frac{1}{4} - r^2 \right] N$$

(b) Now if dy is the elongation in the element of length dr at position r then strain

$$\frac{dy}{dr} = \frac{stress}{Y} = \frac{T}{AY} = \frac{1}{2} \frac{\rho \omega^2}{Y} [L^2 - r^2] dr$$

So the elongation of the whole rod

$$\Delta L = \frac{\rho \omega^2}{2Y} \int_0^L \left(L^2 - r^2\right) \ dr = \frac{1}{3} \ \frac{\rho \omega^2 L^3}{Y} = \frac{1}{3} \times \frac{10^4 \times \left(400\right)^2 \left(0.5\right)^3}{2 \times 10^{11}} = \frac{1}{3} \times 10^{-3} \, \text{m}$$

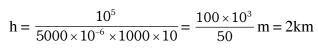
Ex. Find the depth of lake at which density of water is 1% greater than at the surface. Given compressibility $K = 50 \times 10^{-6}$ /atm.

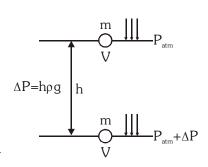
Sol. B =
$$\frac{\Delta P}{-\Delta V/V}$$
 $\Rightarrow \frac{\Delta V}{V} = -\frac{\Delta P}{B}$

We know $P = P_{atm} + h\rho g$ and $m = \rho V = constant$

$$d\rho V + dV \rho = 0 \ \Rightarrow \ \frac{d\rho}{\rho} \ = - \ \frac{dV}{V} \ i.e. \ \frac{\Delta\rho}{\rho} \ = \frac{\Delta P}{B} \ \Rightarrow \ \frac{\Delta\rho}{\rho} \ = \frac{1}{100} = \frac{h\rho g}{B}$$

[assuming ρ = constant]; $h\rho g = \frac{B}{100} = \frac{1}{100K} \Rightarrow h\rho g = \frac{1 \times 1 \times 10^5}{100 \times 50 \times 10^{-6}}$



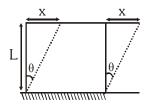


1/10.10.100.245/DTROathvod60/2020.21(18080-8A)/Keb/UELAdvarad/Wodde Coding(V-Tag)/Laode*NPysis/Themad Physics/Themad Physics/Desicity, Codor, & Themad Exp. 65

- 8
- Ex. A rubber cube of side 5 cm has one side fixed while a tangential force equal to 1800 N is applied to opposite face. Find the shearing strain and the lateral displacement of the strained face. Modulus of rigidity for rubber is 2.4×10^6 N/m².

Sol. Stress =
$$\frac{F}{A} = \eta \frac{x}{L}$$

Strain =
$$\theta = \frac{F}{An} = \frac{1800}{25 \times 10^{-4} \times 2.4 \times 10^{6}} = \frac{180}{25 \times 24} = \frac{3}{10} = 0.3 \text{ radian}$$



as
$$\frac{x}{L} = 0.3 \Rightarrow x = 0.3 \times 4 \times 10^{-2} = 1.5 \times 10^{-2} \text{ m} = 1.5 \text{ mm}$$

EFFECT OF TEMPERATURE ON ELASTICITY

When temperature is increased then due to weakness of inter molecular force the elastic properties in general decreases i.e. elastic constant decreases. Plasticity increases with temperature. For example, at ordinary room temperature, carbon is elastic but at high temperature, carbon becomes plastic. Lead is not much elastic at room temperature but when cooled in liquid nitrogen exhibit highly elastic behaviour. For a special kind of steel, elastic constants do not vary appreciably temperature. This steel is called 'INVAR steel'.

EFFECT OF IMPURITY ON ELASTICITY

Y is slightly increase by impurity. The inter molecular attraction force inside wire effectively increase by impurity due to this external force can be easily opposed.

TEMPERATURE

Temperature is a macroscopic physical quantity related to our sense of hot and cold.

TEMPERATURE & DIFFERENT TYPE OF TEMPERATURE SCALES

The natural flow of heat is from higher temperature to lower temperature, i.e. temperature determines the thermal state of a body whether it can give or receive heat.

DIFFERENT TYPES OF TEMPERATURE SCALES

- The Kelvin temperature scale is also known as thermodynamic scale. The SI unit of temperature is the kelvin and is defined as (1/273.16) of the temperature of the triple point of water. The triple point of water is that point on a P-T diagram where the three phase of water, the solid, the liquid and the gas, can coexist in equilibrium.
- In addition to Kelvin temperature scale, there are other temperature scales also like Celsius, Fahrenheit, Reaumur, Rankine, etc. Temperature on one scale can be converted into other scale by using the following identity

$$\frac{\text{Reading on any scale - lower fixed point (LFP)}}{\text{Upper fixed point (UFP) - lower fixed point (LFP)}} = \text{constant for all scales}$$

Hence
$$\frac{C - 0^{\circ}}{100^{\circ} - 0^{\circ}} = \frac{F - 32^{\circ}}{212^{\circ} - 32^{\circ}} = \frac{K - 273.15}{373.15 - 273.15}$$

Different temperature scales:

Name of the scale	Symbol for each degree	Lower fixed point (LFP)	Upper fixed point (UFP)	Number of divisions on the scale
Celsius	$^{\circ}$ C	0℃	100°C	100
Fahrenheit	°F	32°F	212°F	180
Kelvin	K	273.15 K	373.15 K	100

Ex. Express a temperature of 60°F in degree celsius and in kelvin.

Sol. By using
$$\frac{C - 0^{\circ}}{100^{\circ} - 0^{\circ}} = \frac{F - 32^{\circ}}{212^{\circ} - 32^{\circ}} = \frac{K - 273.15}{373.15 - 273.15}$$

$$\Rightarrow \frac{C - 0^{\circ}}{100^{\circ} - 0^{\circ}} = \frac{60^{\circ} - 32^{\circ}}{212^{\circ} - 32^{\circ}} = \frac{K - 273.15}{373.15 - 273.15} \Rightarrow C = 15.15^{\circ} C \text{ and } K = 288.7 K$$

The temperature of an iron piece is heated from 30° to 90°C. What is the change in its temperature on the fahrenheit scale and on the kelvin scale?

Sol.
$$\Delta C = 90^{\circ} - 30^{\circ} = 60^{\circ} C$$

Temperature difference on Fahrenheit Scale $\Delta F = \frac{9}{5}\Delta C = \frac{9}{5}(60^{\circ}C) = 108^{\circ}F$ Temperature difference on Kelvin Scale $\Delta K = \Delta C = 60K$

1/10, 10.100.245/DTR0ah/vode6/2020-21(8080-84)/KohVEELAdvarad/Wodde Coding(V-Tag/Laada-Nhysis VThemal Hysis-VEngish/O_Elaakaiy,Codori, & Themal Exp. 465

THERMAL EXPANSION

THERMAL EXPANSION

When matter is heated without any change in it's state, it usually expands. According to atomic theory of matter, asymmetry in potential energy curve is responsible for thermal expansion. As with rise in temperature the amplitude of vibration increases and hence energy of atoms increases, hence the average distance between the atom increases. So the matter as a whole expands.

- Thermal expansion is minimum in case of solids but maximum in case of gases because intermolecular force is maximum in solids but minimum in gases.
- Solids can expand in one dimension (Linear expansion), two dimension (Superficial expansion) and three dimension (Volume expansion) while liquids and gases usually suffers change in volume only.

Linear expansion:

Superficial (areal) expansion:

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

$$Also \quad A_0 = \ell_0^2 \text{ and } A = \ell^2$$

$$So \quad \ell^2 = \ell_0^2 (1 + \beta \Delta \theta) = [\ell_0 (1 + \alpha \Delta \theta)]^2 \Rightarrow \beta = 2\alpha$$

Volume expansion:

$$V = V_0 (1 + \gamma \Delta \theta) \text{ Also } V = \ell^3 \text{ and } V_0 = \ell_0^3 \text{ so } \gamma = 3\alpha$$

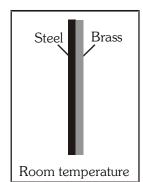
$$\Rightarrow 6\alpha = 3\beta = 2\gamma \text{ or } \alpha : \beta : \gamma = 1 : 2 : 3$$

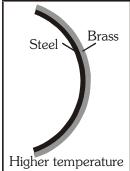
Contraction on heating:

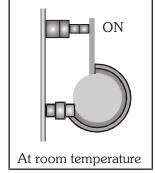
Some rubber like substances contract on heating because transverse vibration of atoms of substance dominate over longitudinal vibration which is responsible for expansion.

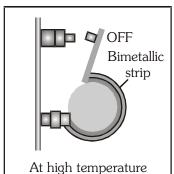
Application of thermal Expansion in Solids

(a) **Bi–metallic strip :** Two strips of equal length but of different materials (different coefficient of linear expansion) when join together, it is called "Bi–metallic strip" and can be used in thermostat to break or make electrical contact. This strip has the characteristic property of bending on heating due to unequal linear expansion of the two metals. The strip will bend with metal of greater α on outer side.





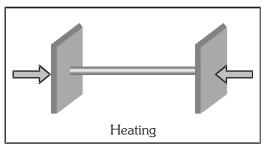


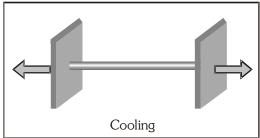


(b) Effect of temperature on the time period of a simple pendulum: A pendulum clock keeps proper time at temperature θ . If temperature is increased to $\theta'(>\theta)$ then due to linear expansion, length of pendulum increases and hence its time period will increase.

Fractional change in time period $\frac{\Delta T}{T} = \frac{1}{2}\alpha\Delta\theta$ (: $T \propto \sqrt{\ell}$: $\frac{\Delta T}{T} = \frac{1}{2}\frac{\Delta\ell}{\ell}$)

- Due to increment in its time period, a pendulum clock becomes slow in summer and will lose time. Loss of time in a time period $\Delta T = \frac{1}{2} \alpha \Delta \theta T$
- The clock will lose time i.e. will become slow if $\theta' > \theta$ (in summer) and will gain time i.e will become fast if $\theta' < \theta$ (in winter).
- Since coefficient of linear expansion (α) is very small for invar, hence pendulums are made of invar to show the correct time in all seasons.
- When a rod whose ends are rigidly fixed such as to prevent expansion or contraction, (c) undergoes a change in temperature due to thermal expansion or contraction, a compressive or tensile stress is developed in it. Due to this thermal stress the rod will exert a large force on the supports. If the change in temperature of a rod of length L is $\Delta\theta$ then :-





Thermal strain =
$$\frac{\Delta L}{L} = \alpha \Delta \theta$$
 $\therefore \alpha = \frac{\Delta L}{L} \times \frac{1}{\Delta \theta}$ So thermal stress = $Y\alpha\Delta\theta$

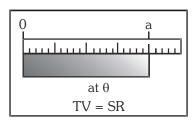
$$\alpha = \frac{\Delta L}{L} \times \frac{1}{\Delta \theta}$$

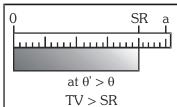
So thermal stress =
$$Y\alpha\Delta\theta$$

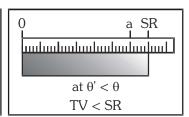
$$\therefore Y = \frac{stress}{strain}$$

So force on the supports $F=YA\alpha\Delta\theta$

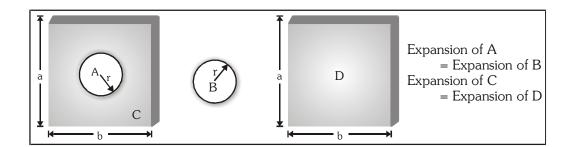
Error in scale reading due to expansion or contraction: If a scale gives correct reading **(d)** at temperature θ . At temperature $\theta'(>\theta)$ due to linear expansion of scale, the scale will expand and scale reading will be lesser than true value so that,







(e) Expansion of cavity: Thermal expansion of an isotropic object may be imagined as a photographic enlargement.



(f) Some other application

- When rails are laid down on the ground, space is left between the ends of two rails
- The transmission cable are not tightly fixed to the poles
- Test tubes, beakers and cubicles are made of pyrex-glass or silica because they have very low value of coefficient of linear expansion
- The iron rim to be put on a cart wheel is always of slightly smaller diameter than that of wheel
- A glass stopper jammed in the neck of a glass bottle can be taken out by warming the neck of the bottle.
- Ex. A steel ruler exactly 20 cm long is graduated to give correct measurements at 20° C. $(\alpha_{\text{steel}} = 1.2 \times 10^{-5} \, {}^{\circ}\text{C}^{-1})$
 - (a) Will it give readings that are too long or too short at lower temperatures?
 - (b) What will be the actual length of the ruler be when it is used in the desert at a temperature of 40° C?
- **Sol.** (a) If the temperature decreases, the length of the ruler also decreases through thermal contraction. Below 20°C, each centimeter division is actually somewhat shorter than 1.0 cm, so the steel ruler gives readings that are too long.
 - (b) At 40°C, the increases in length of the ruler is

$$\Delta \ell = \ell \alpha \Delta T = (20) (1.2 \times 10^{-5}) (40^{\circ} - 20^{\circ}) = 0.48 \times 10^{-2} \text{ cm}$$

- : The actual length of the ruler is, $\ell'=\ell+\Delta\ell=20.0048$ cm
- Ex. A second's pendulum clock has a steel wire. The clock is calibrated at 20°C. How much time does the clock lose or gain in one week when the temperature is increased to 30° C? ($\alpha_{\text{steel}} = 1.2 \times 10^{-5} \, {}^{\circ}$ C⁻¹)
- **Sol.** The time period of second's pendulum is 2 second. As the temperature increases length time period increases. Clock becomes slow and it loses the time. The change in time period is

$$\Delta T = \frac{1}{2} T \alpha \Delta \theta = \left(\frac{1}{2}\right) (2) (1.2 \times 10^{-5}) (30^{\circ} - 20^{\circ}) = 1.2 \times 10^{-4} \text{ s}$$

.. New Time period is

$$T' = T + \Delta T = (2 + 1.2 \times 10^{-4}) = 2.00012 \text{ s}$$

: Time lost in one week

$$\Delta t = \left(\frac{\Delta T}{T'}\right) t = \frac{(1.2 \times 10^{-4})}{(2.00012)} (7 \times 24 \times 3600) = 36.28 \text{ s}$$

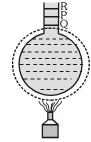
Water at

temperature t°C

Melting ice

Thermal Expansion in Liquids

- Liquids do not have linear and superficial expansion but these only have volume expansion.
- Since liquids are always to be heated along with a vessel which contains them so initially on heating the system (liquid + vessel), the level of liquid in vessel falls (as vessel expands more since it absorbs heat and liquid expands less) but later on, it starts rising due to faster expansion of the liquid.



 $PQ \rightarrow$ represents expansion of vessel

 $QR \rightarrow$ represents the real expansion of liquid.

- The actual increase in the volume of the liquid
 - = The apparent increase in the volume of liquid + the increase in the volume of the vessel.
- Liquids have two coefficients of volume expansion.

(i) Co-efficient of apparent expansion (γ_a)

• It is due to apparent (that appears to be, but in not) increase in the volume of liquid if expansion of vessel containing the liquid is not taken into account.

$$\gamma_{a} = \frac{Apparent\ expansion\ in\ volume}{Initial\ volume\ \times \Delta\theta} = \frac{(\Delta V)}{V \times \Delta\theta}$$

(ii) Co-efficient of real expansion (γ_r)

• It is due to the actual increase in volume of liquid due to heating.

$$\gamma_{\rm r} = \frac{\text{Real increase in volume}}{\text{Initial volume} \times \Delta \theta} = \frac{(\Delta V)}{V \times \Delta \theta}$$

- Also coefficient of expansion of flask $\gamma_{Vessel} = \frac{(\Delta V)_{Vessel}}{V \times \Delta \theta}$
- $\gamma_{\text{Real}} = \gamma_{\text{Apparent}} + \gamma_{\text{Vessel}}$

• Change (apparent change) in volume in liquid relative to vessel is

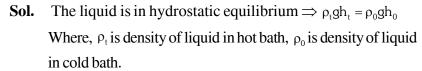
$$\Delta V_{app} {= V(\gamma_{Real} - \gamma_{Vessel}) \ \Delta \theta = V(\gamma_r - 3\alpha) \Delta \theta}$$

 α = Coefficient of linear expansion of the vessel.

• Different level of liquid in vessel

γ	ΔV	Level	
$\gamma_{\text{Real.}} > \gamma_{\text{Vessel}} (= 3\alpha) \Rightarrow \gamma_{\text{app}} > 0$	ΔV_{app} is positive	Level of liquid in Vessel will rise on heating	
$\gamma_{\text{Re al}} < \gamma_{\text{Vessel}} (= 3\alpha) \Rightarrow \gamma_{\text{app}} < 0$	ΔV_{app} is negative	Level of liquid in vessel will fall on heating	
$\gamma_{Real} = \gamma_{Vessel} (= 3\alpha) \Rightarrow \gamma_{app} = 0$	$\Delta V_{app} = 0$	Level of liquid in vessel will remain same	

Ex. In figure shown, left arm of a U-tube is immersed in a hot water bath at temperature t°C, and right arm is immersed in a bath of melting ice; the height of manometric liquid in respective columns is h_t and h₀. Determine the coefficient of expansion of the liquid.



Volumes of a given mass M of liquid at temperatures t and 0°C

are related by
$$V_t = V_0(1+\gamma t)$$
 Since $\rho_t V_t = \rho_0 V_0 \implies \rho_t = \frac{\rho_0 V_0}{V_t} = \frac{\rho_0}{(1+\gamma t)}$

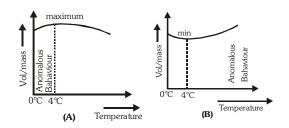
Since $h_t = \frac{\rho_0 h_0}{\rho_t} = h_0 (1 + \gamma t)$ which on solving for γ , yields $\gamma = \frac{\left(h_t - h_0\right)}{h_0 t}$



14

Anomalous expansion of water

Generally matter expands on heating and contracts on cooling. In case of water, it expands on heating if its temperature is greater than 4°C. In the range 0°C to 4°C, water contracts on heating and expands on cooling, i.e. γ is negative. This behaviour of water in the range from 0°C to 4°C is called anomalous expansion.



This anomalous behaviour of water causes ice to form first at the surface of a lake in cold weather. As winter approaches, the water temperature increases initially at the surface. The water there sinks because of its increased density. Consequently, the surface reaches 0°C first and the lake becomes covered with ice. Aquatic life is able to survive the cold winter as the lake bottom remains unfrozen at a temperature of about 4°C. At 4°C, density of water is maximum while its specific volume is minimum.

- **Ex.** The difference between lengths of a certain brass rod and of a steel rod is claimed to be constant at all temperatures. Is this possible?
- **Sol.** If L_B and L_S are the lengths of brass and steel rods respectively at a given temperature, then the lengths of the rods when temperature is changed by θ °C.

$$L'_{_B} = L_{_B}(1 + \alpha_{_B} \, \Delta \theta) \text{ and } L'_{_S} = L_{_S}(1 + \alpha_{_B} \, \Delta \theta) \qquad \text{So that } L'_{_B} = L'_{_S}(L_{_B} \, - L_{_S}) + (L_{_B} \, \alpha_{_B} - L_{_S}\alpha_{_S}) \, \Delta \theta$$

So
$$(L'_B - L'_S)$$
 will be equal to $(L_B - L_S)$ at all temperatures if , $L_B \alpha_B - L_S \alpha_S = 0$ [as $\Delta\theta \neq 0$] or $\frac{L_B}{L_S} = \frac{\alpha_S}{\alpha_B}$

i.e., the difference in the lengths of the two rods will be independent of temperature if the lengths are in the inverse ratio of their coefficients of linear expansion.

- **Ex.** There are two spheres of same radius and material at same temperature but one being solid while the other hollow. Which sphere will expand more if
 - (a) they are heated to the same temperature, (b) same heat is given to them?
- **Sol.** (a) As thermal expansion of isotropic solids is similar to true photographic enlargement, expansion of a cavity is same as if it had been a solid body of the same material





i.e.
$$\Delta V = V \gamma \Delta \theta$$

As here V, γ and $\Delta\theta$ are same for both solid and hollow spheres treated (cavity); so the expansion of both will be equal.

(b) If same heat is given to the two spheres due to lesser mass, rise in temperature of hollow sphere will be more [as $\Delta\theta = \frac{Q}{mc}$] and hence its expansion will be more [as $\Delta V = V\gamma\Delta\theta$].



CALORIMETARY

HEAT

When a hot body is put in contact with a cold one, the former gets colder and the latter warmer. From this observation it is natural to conclude that a certain quantity of heat has passed from the hot body to the cold one. Heat is a form of energy.

Heat is felt by its effects. Some of the effects of heat are:

- (a) Change in the degree of hotness
- (b) Expansion in length, surface area and volume
- (c) Change in state of a substance
- (d) Change in the resistance of a conductor

(e) Thermo e.m.f. effect

SI UNIT: J (joule) Also measured in the unit calorie.

Calorie

It is defined as the amount of heat required to raise the temperature of 1 g water by 1°C.

• International calorie

International calorie is the amount of heat required to raise the temperature of 1g water from 14.5 °C to 15.5 °C rise of temperature.

Kilo Calorie

Kilo calorie is defined as the amount of heat required to raise the temperature of 1 kg water from 14.5 °C to 15.5 °C. (1 kcal = 1000 calorie).

• British thermal unit (B. T. U.)

It is the amount of heat required to raise the temperature of one pound water by 1° F. (1 B.T.U. = 252 calorie).

MECHANICAL EQUIVALENT OF HEAT

According to Joule, work may be converted into heat and vice-versa. The ratio of work done to heat

produced is always constant.
$$\frac{W}{H} = \text{constant } (J) \Rightarrow W = J H$$

W must be in joule, irrespective of nature of energy or work and H must be in calorie.

J is called mechanical equivalent of heat. It is not a physical quantity but simply a conversion factor.

It converts unit of work into that of heat and vice-versa.

J = 4.18 joule/cal or 4.18×10^3 joule per kilo-cal. For rough calculations we take J = 4.2 joule/cal

SPECIFIC HEAT (s or c)

It is the amount of energy required to raise the temperature of unit mass of that substance by 1° C (or 1K) is called specific heat. It is represented by s or c.

If the temperature of a substance of mass m changes from T to T + dT when it exchanges an amount of heat dQ with its surroundings then its specific heat is $c = \frac{1}{m} \frac{dQ}{dT}$

16

The specific heat depends on the pressure, volume and temperature of the substance.

For liquids and solids, specific heat measurements are most often made at a constant pressure as functions of temperature, because constant pressure is quite easy to produce experimentally.

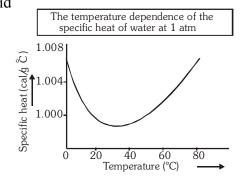
SI UNIT:

CGS UNIT :
$$cal/g - ^{\circ}C$$

Specific heat of water : $c_{water} = 1 \text{ cal/g} - {}^{\circ}\text{C} = 1 \text{ cal/g} - \text{K} = 1 \text{ kcal/kg} - \text{K} = 4200 \text{ joule/kg} - \text{K}$

When a substance does not undergo a change of state (i.e., liquid remains liquid or solid remains solid), then the amount of heat required to raise the temperature of mass m of the substance by an amount $\Delta\theta$ is $Q = ms\Delta\theta$.

The temperature dependence of the specific heat of water at 1 atmospheric pressure is shown in figure. Its variation is less than 1% over the interval from 0 to 100°C. Such a small variation is typical for most solids and liquids, so their specific heats can generally be taken to be constant over fairly large temperature ranges.



- There are many processes possible to give heat to a gas.
 A specific heat can be associated to each such process which depends on the nature of process.
- Value of specific heats can vary from zero (0) to infinity.
- Generally two types of specific heat are mentioned for a gas –
 (a) Specific heat at constant volume (C_v) (b) Specific heat at constant pressure (C_p)
- These specific heats can be molar or gram.

MOLAR HEAT CAPACITY

The amount of energy needed to raise the temperature of one mole of a substance by 1° C (or 1K) is called molar heat capacity. The molar heat capacity is the product of molecular weight and specific heat i.e.,

Molar heat capacity C = Molecular weight (M) × Specific heat(c) \Rightarrow C = $\frac{1}{\mu} \left(\frac{dQ}{dT} \right)$

If the molecular mass of the substance is M and the mass of the substance is m then number of moles of the

substance $\mu = \frac{m}{M} \Rightarrow C = \frac{M}{m} \left(\frac{dQ}{dT} \right)$

THERMAL CAPACITY

The quantity of heat required to raise the temperature of the whole of that substance through 1° C is called thermal capacity. The thermal capacity of mass m of the whole of substance of specific heat s is = ms

Thermal capacity = $mass \times specific heat$

Thermal capacity depends on property of material of the body and mass of the body.

SI UNIT: cal/°C or cal/K, **Dimensions**: ML² T⁻²K⁻¹

WATER EQUIVALENT OF A BODY

As the specific heat of water is unity so the thermal capacity of a body (ms) represents its water equivalent also.

- Mass of water having the same thermal capacity as the body is called the water equivalent of the body
- The water equivalent of a body is the amount of water that absorbs or gives out the same amount of heat as is done by the body when heated or cooled through 1°C.

Water equivalent= mass of body \times specific heat of the material \Rightarrow (w = ms).

LATENT HEAT OR HIDDEN HEAT

When state of a body changes, change of state takes place at constant temperature [melting point or boiling point] and heat released or absorbed is Q = mL where L is latent heat. Heat is absorbed if solid converts into liquid (at melting point) or liquid converts into vapours (at boiling point) and heat is released if liquid converts into solid or vapours converts into liquid.

Latent heat of fusion

It is the quantity of heat (in kilocalories) required to change its 1 kg mass from solid to liquid state at its melting point. Latent heat of fusion for ice: 80 kcal/kg = 80 cal/g.

Latent heat of vaporization

The quantity of heat required to change its 1 kg mass from liquid to vapour state at its boiling point. Latent heat of vaporisation for water : 536 kcal/kg = 536 cal/g

CHANGE OF STATE

Melting

Conversion of solid into liquid state at constant temperature is known as melting.

Boiling

Evaporation within the whole mass of the liquid is called boiling. Boiling takes place at a constant temperature known as boiling point. A liquid boils when the saturated vapour pressure on its surface is equal to atmospheric pressure. Boiling point reduces on decreasing pressure.

Evaporation

Conversion of liquid into vapours at all temperatures is called evaporation. It is a surface phenomenon. Greater the temperature, faster is the evaporation. Smaller the boiling point of liquid, more rapid is the evaporation. Smaller the humidity, more is the evaporation. Evaporation increases on decreasing pressure that is why evaporation is faster in vacuum.

Heat of evaporation

Heat required to change unit mass of liquid into vapour at a given temperature is called heat of evaporation at that temperature.

Sublimation

Direct conversion of solid in to vapour state is called sublimation.

Heat of sublimation

Heat required to change unit mass of solid directly into vapours at a given temperature is called heat of sublimation at that temperature.

- Camphor and ammonium chloride sublimates on heating in normal conditions.
- A block of ice sublimates into vapours on the surface of moon because of very-very low pressure on its surface

Condensation

The process of conversion from gaseous or vapour state to liquid state is known as condensation.

These materials again get converted to vapour or gaseous state on heating.

Hoar frost

Direct conversion of vapours into solid is called hoar frost. This process is just reverse of the process of sublimation.

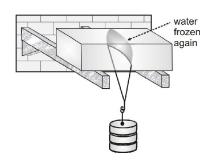
Ex.: Formation of snow by freezing of clouds.

Regelation

Regelation is the melting of ice caused by pressure and its resolidification when the pressure is removed. Ice shrinks when it melts, and if pressure is applied, deliberately promoting shrinkage, it is found that melting is thereby assisted. In other words, melting of cold ice is ordinarily effected by raising the temperature, but if pressure is present to help with the shrinkage the temperature need not be raised so much.

Ice heals up after being cut through by the wire. Melting takes place under the wire because pressure lowers the melting temperature. Refreezing (regelation) occurs above the wire when the water escapes to normal pressure again.

Increase of pressure lowers the melting (or freezing) point of water. Conversely, if a substance expands on melting, the melting point is raised by pressure.



PHASE OF A SUBSTANCE

The phase of a substance is defined as its form which is homogeneous, physically distinct and mechanically separable from the other forms of that substance.

Phase diagram

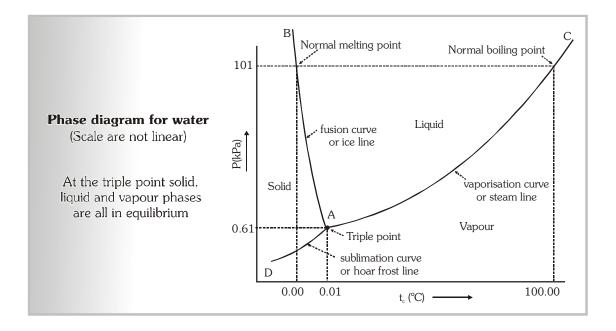
• A phase diagram is a graph in which pressure (P) is represented along the y-axis and temperature (T) is represented along the x-axis.

• Characteristics of Phase diagram

- (i) Different phases of a substances can be shown on a phase diagram.
- (ii) A region on the phase diagram represents a single phase of the substance, a curve represents equilibrium between two phases and a common point represents equilibrium between three phases.
- (iii) A phase diagram helps to determine the condition under which the different phases are in equilibrium.
- (iv) A phase diagram is useful for finding a convenient way in which a desired change of phase can be produced.

PHASE DIAGRAM FOR WATER

The phase diagram for water consists of three curves AB, AC and AD meeting each other at the point A, these curves divide the phase diagram into three regions.



Region to the left of the curve AB and above the curve AD represents the solid phase of water (ice). The region to the right of the curve AB and above the curve AC represents the liquid phase of water. The region below the curves AC and AD represents the gaseous phase of water (i.e. water vapour). A curve on the phase diagram represents the boundary between two phases of the substance.

Along any curve the two phases can coexist in equilibrium

- Along curve AB, ice and water can remain in equilibrium. This curve is called fusion curve or ice line. This curve shows that the melting point of ice decreases with increase in pressure.
- Along the curve AC, water and water vapour can remain in equilibrium. The curve is called vaporisation curve or steam line. *The curve shows that the boiling point of water increases with increase in pressure.*
- Along the curve AD, ice and water vapour can remain in equilibrium.

This curve is called sublimation curve or hoar frost line.

TRIPLE POINT OF WATER

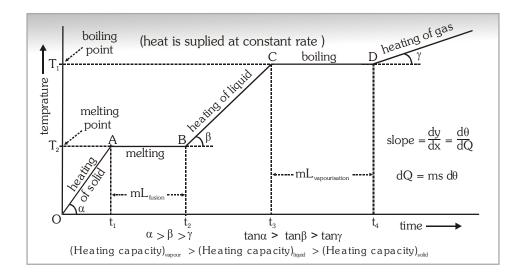
The three curves in the phase diagram of water meet at a single point A, which is called the triple point of water. The triple point of water represents the co–existance of all the three phases of water ice water and water vapour in equilibrium. The pressure corresponding to triple point of water is 6.03×10^{-3} atmosphere or 4.58 mm of Hg and temperature corresponding to it is 273.16K.

• Significance of triple point of water

Triple point of water represents a unique condition and it is used to define the absolute temperature. While making Kelvin's absolute scale, upper fixed point is 273.16 K and lower fixed point is 0 K. One kelvin of

temperature is fraction $\frac{1}{273.16}$ of the temperature of triple point of water.

If to a given mass (m) of a solid, heat is supplied at constant rate and a graph is plotted between temperature and time as shown in figure is called heating curve.



• In the region OA

Rate of heat supply P is constant and temperature of solid is changing with time

So,
$$Q = mc_s \Delta T \Rightarrow P \Delta t = mc_s \Delta T$$
 [: $Q = P \Delta t$] : $\frac{\Delta T}{\Delta t}$ = The slope of temperature—time curve so specific

heat of solid $c_s \propto \frac{1}{\text{slope of line OA}}$ specific heat (or thermal capacity) is inversely proportional to the slope of temperature—time curve.

• In the region AB

Temperature is constant, so it represents change of state, i.e., melting of solid with melting point T_1 . At point A melting starts and at point B all solid is converted into liquid. So between A and B substance is partly solid and partly liquid. If L_F is the latent heat of fusion then

$$Q = mL_F \Rightarrow L_F = \frac{P(t_2 - t_1)}{m}$$
 [as $Q = P(t_2 - t_1] \Rightarrow L_F \propto \text{length of line AB}$

i.e., Latent heat of fusion is proportional to the length of line of zero slope.

[In this region specific heat $\propto \frac{1}{\tan 0^{\circ}} = \infty$]

• In the region BC

Temperature of liquid increases so specific heat (or thermal capacity) of liquid will be inversely proportional

to the slope of line BC,
$$c_L \propto \frac{1}{\text{slope of line BC}}$$

• In the region CD

Temperature in constant, so it represents change of state, i.e., liquid is boiling with boiling point T_2 . At C all substance is in liquid state while at D is vapour state and between C and D partly liquid and partly gas. The length of line CD is proportional to latent heat of vaporisation, i.e., $L_v \propto L_v \propto L_v$

[In this region specific heat
$$\propto \frac{1}{\tan 0^{\circ}} = \infty$$
]

The line DE represents gaseous state of substance with its temperature increasing linearly with time. The reciprocal of slope of line will be proportional to specific heat or thermal capacity of substance in vapour state.

LAW OF MIXTURES

- When two bodies (one being solid and other liquid or both being liquid) at different temperatures are mixed, heat will be transferred from body at higher temperature to a body at lower temperature till both acquire same temperature. The body at higher temperature released heat while body at lower temperature absorbs it, so that Heat lost = Heat gained. Principle of calorimetry represents the law of conservation of heat energy.
- Temperature of mixture (T) is always \geq lower temperature (T_L) and \leq higher temperature (T_H), $T_L \leq T \leq T_H$

The temperature of mixture can never be lesser than lower temperature (as a body cannot be cooled below the temperature of cooling body) and greater than higher temperature (as a body cannot be heated above the temperature of heating body). Further more usually rise in temperature of one body is not equal to the fall temperature of the other body though heat gained by one body is equal to the heat lost by the other.

- Ex. 5g ice at 0°C is mixed with 5g of steam at 100°C. What is the final temperature?
- **Sol.** Heat required by ice to raise its temperature to 100°C,

$$Q_1 = m_1 L_1 + m_1 c_1 \Delta \theta_1 = 5 \times 80 + 5 \times 1 \times 100 = 400 + 500 + 900 = 1800 \text{ cal}$$

Heat given by steam when condensed $Q_2 = m_2L_2 = 5 \times 536 = 2680$ cal

As $Q_2 > Q_1$. This means that whole steam is not even condensed.

Hence temperature of mixture will remain at 100°C.

- **Ex.** A calorimeter of heat capacity 100 J/K is at room temperature of 30°C. 100 g of water at 40°C of specific heat 4200 J/kg–K is poured into the calorimeter. What is the temperature of water in calorimeter?
- **Sol.** Let the temperature of water in calorimeter is t. Then heat lost by water = heat gained by calorimeter

$$(0.1) \times 4200 \times (40 - t) = 100 (t - 30) \implies 42 \times 40 - 42t = 10t - 300 \implies t = 38.07^{\circ}C$$

Ex. Find the quantity of heat required to convert $40 \,\mathrm{g}$ of ice at $-20 \,\mathrm{^{\circ}C}$ into water at $20 \,\mathrm{^{\circ}C}$.

Given
$$L_{ice} = 0.336 \times 10^6$$
 J/kg. Specific heat of ice = 2100 J/kg-K,

specific heat of water = 4200 J/kg-K

1/10.10.100.245/DTPDatavode06/2020-218080-84)/Keb/JEELAdvanad/Woddle Coding/V-Tog/Neader/Physis \Themad Bysp65

Sol. Heat required to raise the temperature of ice from -20° C to 0° C = $0.04 \times 2100 \times 20 = 1680$ J

Heat required to convert the ice into water at 0° C = mL = $0.04 \times 0.336 \times 10^{6} = 13440$ J

Heat required to heat water from 0° C to 20° C = $0.04 \times 4200 \times 20 = 3360$ J

Total heat required = 1680 + 13440 + 3360 = 18480 J

- Ex. Steam at 100°C is passed into 1.1 kg of water contained in a calorimeter of water equivalent 0.02 kg at 15°C till the temperature of the calorimeter and its contents rises to 80°C. What is the mass of steam condensed? Latent heat of steam = 536 cal/g.
- **Sol.** Heat required by (calorimeter + water)

Q =
$$(m_1c_1 + m_2c_2) \Delta\theta = (0.02 + 1.1 \times 1) (80 - 15) = 72.8 \text{ kcal}$$

If m is mass of steam condensed, then heat given by steam

$$Q = mL + mc \Delta\theta = m \times 536 + m \times 1 \times (100 - 80) = 556 \text{ m}$$
 $\therefore 556 \text{ m} = 72.8$

∴ Mass of steam condensed
$$m = \frac{72.8}{556} = 0.130 \text{ kg}$$

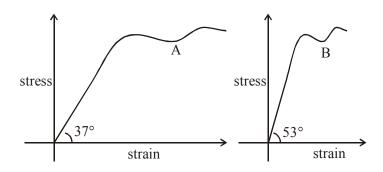
EXERCISE (S)

Elasticity:

1. A steel wire of length 4.5 m and a copper wire of length 3.5 m are stretched same amount under a given load. If ratio of youngs modulli of steel to that of copper is $\frac{12}{7}$, then what is the ratio of cross sectional area of steel wire to copper wire?

EH0001

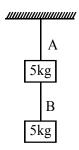
2. Diagram shows stress-strain graph for two material A & B. The graphs are drawn to scale.



The ratio of young modulli of material A to material B is.

EH0002

3. Two identical wires A & B of same material are loaded as shown in figure. If the elongation in wire B is 1.5 mm, what is the elongation in A. (Mass of A & B can be neglected)

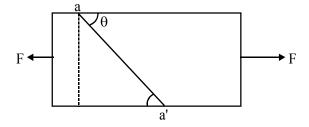


EH0003

4. A wire of length L and radius r is clamped rigidly at one end. When the other end of the wire is pulled by a force f, its length increases by l. Another wire of the same material of length 2L and radius 2r, is pulled by a force 2f. Find the increase in length of this wire.

EH0004

5. Consider a long steel bar under a tensile stress due to forces \vec{F} acting at the edges along the length of the bar (Fig.). Consider a plane making an angle θ with the length. What are the tensile and shearing stresses on this plane?



- (a) For what angle is the tensile stress a maximum?
- (b) For what angle is the shearing stress a maximum?

EH0005

6. A light rigid bar AB is suspended horizontally from two vertical wires, one of steel and one of brass, as shown in figure. Each wire is 2.00 m long. The diameter of the steel wire is 0.60 mm and the length of the bar AB is 0.20 m. When a mass of 10 kg is suspended from the centre of AB bar remains horizontal.



- (i) What is the tension in each wire?
- (ii) Calculate the extension of the steel wire and the energy stored in it.
- (iii) Calculate the diameter of the brass wire.
- (iv)If the brass wire were replaced by another brass wire of diameter 1 mm, where should the mass be suspended so that AB would remain horizontal? The Young modulus for steel = 2.0×10^{11} Pa, the Young modulus for brass = 1.0×10^{11} Pa.

EH0006

Calorimetry:

7. One day in the morning, Ramesh filled up 1/3 bucket of hot water from geyser, to take bath. Remaining 2/3 was to be filled by cold water (at room temperature) to bring mixture to a comfortable temperature. Suddenly Ramesh had to attend to something which would take some times, say 5-10 minutes before he could take bath. Now he had two options: (i) fill the remaining bucket completely by cold water and then attend to the work, (ii) first attend to the work and fill the remaining bucket just before taking bath. Which option do you think would have kept water warmer? Explain.

EH0007

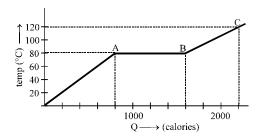
8. The temperature of 100 gm of water is to be raised from 24°C to 90°C by adding steam to it. Calculate the mass of the steam required for this purpose.

EH0013

9. An aluminium container of mass 100 gm contains 200 gm of ice at -20° C. Heat is added to the system at the rate of 100 cal/s. Find the temperature of the system after 4 minutes (specific heat of ice = 0.5 and L = 80 cal/gm, specific heat of Al = 0.2 cal/gm/ $^{\circ}$ C)

EH0008

10. A substance is in the solid form at 0°C. The amount of heat added to this substance and its temperature are plotted in the following graph. If the relative specific heat capacity of the solid substance is 0.5, find from the graph



- (i) the mass of the substance;
- (ii) the specific latent heat of the melting process, and
- (iii) the specific heat of the substance in the liquid state.

EH0014

11. A hot liquid contained in a container of negligible heat capacity loses temperature at rate 3 K/min, just before it begins to solidify. The temperature remains constant for 30 min. Find the ratio of specific heat capacity of liquid to specific latent heat of fusion is in K⁻¹ (given that rate of losing heat is constant).

EH0009

12. Two 50 gm ice cubes are dropped into 250 gm of water into a glass. If the water was initially at a temperature of 25° C and the temperature of ice -15° C. Find the final temperature of water. (specific heat of ice = 0.5 cal/gm/°C and L = 80 cal/gm). Find final amount of water and ice.

EH0010

a stream of the liquid as it passes through the calorimeter at a known rate. Then a measurement of the resulting temperature difference between the inflow and the outflow points of the liquid stream enables us to compute the specific heat of the liquid. A liquid of density 0.2 g/cm³ flows through a calorimeter at the rate of 10 cm³/s. Heat is added by means of a 250-W electric heating coil, and a temperature difference of 25°C is established in steady-state conditions between the inflow and the outflow points. Find the specific heat of the liquid.

EH0011

26 JEE-Physics ALLEN

14. Two identical calorimeter A and B contain equal quantity of water at 20° C. A 5 gm piece of metal X of specific heat 0.2 cal g^{-1} (C°)⁻¹ is dropped into A and a 5 gm piece of metal Y into B. The equilibrium temperature in A is 22° C and in B 23° C. The initial temperature of both the metals is 40° C. Find the specific heat of metal Y in cal g^{-1} (C°)⁻¹.

EH0012

Thermal expansion:

15. If two rods of length L and 2 L having coefficients of linear expansion α and 2α respectively are connected so that total length becomes 3 L, determine the average coefficient of linear expansion of the composite rod.

EH0015

16. A clock pendulum made of invar has a period of 0.5 sec at 20°C. If the clock is used in a climate where average temperature is 30°C, approximately. How much fast or slow will the clock run in 10^6 sec. $(\alpha_{invar} = 1 \times 10^{-6})^{\circ}$ C)

EH0016

17. An iron bar (Young's modulus = 10^{11} N/m², $\alpha = 10^{-6}$ /°C) 1 m long and 10^{-3} m² in area is heated from 0°C to 100°C without being allowed to bend or expand. Find the compressive force developed inside the bar.

EH0017

Ε

EXERCISE (O)

SINGLE CORRECT TYPE QUESTIONS

Elasticity:

1. A wire suspended vertically from one of its ends is stretched by attaching a weight of 200 N to the lower ends. The weight stretches the wire by 1mm. Then the elastic energy stored in the wire is-

[AIEEE - 2003]

(A) 0.2 J

(B) 10 J

(C) 20 J

(D) 0.1 J

EH0047

2. The maximum load a wire can withstand without breaking, when its length is reduced to half of its original length, will

(A) be double.

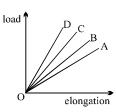
(B) be half.

(C) be four times.

(D) remain same.

EH0042

3. The load versus strain graph for four wires of the same material is shown in the figure. The thickest wire is represented by the line:-



(A) OB

(B) OA

(C) OD

(D) OC

EH0049

4. Overall changes in volume and radii of a uniform cylindrical steel wire are 0.2% and 0.002% respectively when subjected to some suitable force. Longitudinal tensile stress acting on the wire is :- $(Y = 2.0 \times 10^{11} \text{ Nm}^{-2})$

(A) $3.2 \times 10^9 \text{ Nm}^{-2}$

(B) $3.2 \times 10^7 \text{ Nm}^{-2}$

(C) $3.6 \times 10^9 \text{ Nm}^{-2}$

(D) $3.9 \times 10^8 \text{ Nm}^{-2}$

EH0045

5. A solid sphere of radius R made of material of bulk modulus K is surrounded by a liquid in a cylindrical container. A massless piston of area A floats on the surface of the liquid. When a mass m is placed on the piston to compress the liquid, the fractional change in the radius of the sphere $\delta R/R$ is

(A) mg/AK

(B) mg/3AK

(C) mg/A

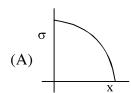
(D) mg/3AR

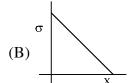
EH0046

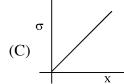
- 6. A wire fixed at the upper end stretches by length ℓ by applying a force F. The work done in stretching is-
 - (A) $\frac{F}{2\ell}$
- (B) $F\ell$
- (C) 2F\(\ell \)
- (D) $\frac{F\ell}{2}$

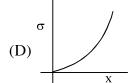
EH0160

7. A uniform rod rotating in gravity free region with certain constant angular velocity. The variation of tensile stress with distance x from axis of rotation is best represented by which of the following graphs.







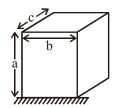


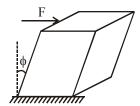
EH0048

- 8. Steel ruptures when a shear of 3.5×10^8 Nm⁻² is applied. The force needed to punch a 1 cm diameter hole in a steel sheet 0.3 cm thick is nearly:- [**JEE-MAINS ONLINE**]
 - $(A)3.3 \times 10^4 \text{ N}$
- (B) $1.4 \times 10^4 \text{ N}$
- (C) $1.1 \times 10^4 \text{ N}$
- (D) $2.7 \times 10^4 \text{ N}$

EH0161

9. A cuboidal block of sides a, b & c is fixed on ground. The top is pushed by a horizontal force F as shown. The angle ϕ by which the block deforms is : (η is modulus of rigidity)





- (A) $\frac{F}{ab\eta}$
- (B) $\frac{F}{acn}$
- (C) $\frac{F}{bcn}$
- (D) $\frac{F}{\sqrt{b^2 + c^2}}$

EH0050

- 10. A cylindrical wire of radius 1 mm, length 1 m, Young's modulus = 2×10^{11} N/m², poisson's ratio $\mu = \pi/10$ is stretched by a force of 100 N. Its radius will become
 - (A) 0.99998 mm
- (B) 0.99999 mm
- (C) 0.99997 mm
- (D) 0.99995 mm

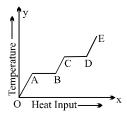
EH0107

Calorimetry:

- 11. Heat is associated with
 - (A) kinetic energy of random motion of molecules.
 - (B) kinetic energy of orderly motion of molecules.
 - (C) total kinetic energy of random and orderly motion of molecules.
 - $(D)\ kinetic\ energy\ of\ random\ motion\ in\ some\ cases\ and\ kinetic\ energy\ of\ orderly\ motion\ in\ other.$

EH0051

12. A solid material is supplied with heat at a constant rate. The temperature of material is changing with heat input as shown in the figure. What does slope DE represents?



(A) latent heat of liquid

(B) latent heat of vapour

(C) heat capacity of vapour

(D) inverse of heat capacity of vapour

EH0056

13. Equal amount of heat energy are transferred into equal mass of ethyl alcohol and water sample. The rise in temperature of water sample is 25°C. The temperature rise of ethyl alcohol will be.

(Specific heat of ethyl alcohol is one half of the specific heat of water).

(A) 12.5° C

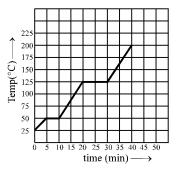
(B) 25°C

(C) 50°C

(D) It depends on the rate of energy transfer.

EH0052

14. The graph shown in the figure represent change in the temperature of 5 kg of a substance as it abosrbs heat at a constant rate of 42 kJ min⁻¹. The latent heat of vapourazation of the substance is :



- (A) 630 kJ kg⁻¹
- (B) 126 kJ kg⁻¹
- (C) 84 kJ kg⁻¹
- (D) 12.6 kJ kg⁻¹

EH0059

- **15.** A block of mass 2.5 kg is heated to temperature of 500° C and placed on a large ice block. What is the maximum amount of ice that can melt (approx.). Specific heat for the body = 0.1 Cal/gm $^{\circ}$ C.
 - (A) 1 kg
- (B) 1.5 kg
- (C) 2 kg
- (D) 2.5 kg

EH0053

- **16.** The density of a material A is 1500 kg/m³ and that of another material B is 2000 kg/m³. It is found that the heat capacity of 8 volumes of A is equal to heat capacity of 12 volumes of B. The ratio of specific heats of A and B will be
 - (A) 1 : 2
- (B) 3:1
- (C) 3:2
- (D) 2:1

EH0060

30	JEE-Physics				ALLEN	
17.	10 gm of ice at 0°C is kept in a calorimeter of water equivalent 10 gm. How much heat should be supplied to the apparatus to evaporate the water thus formed? (Neglect loss of heat)					
	(A) 6200 cal	(B) 7200 cal	(C) 13600 cal	(D) 8200 cal		
					EH0054	
18.	A continuous flow water heater (geyser) has an electrical power rating = 2 kW and efficienty					
	conversion of electrical power into heat $= 80\%$. If water is flowing through the device at the rate of					
	100 cc/sec, and the inlet temperature is 10°C, the outlet temperature will be					

(A) 12.2°C

(B) 13.8°C

(C) 20°C

(D) 16.5°C

EH0055

19. A block of ice with mass m falls into a lake. After impact, a mass of ice m/5 melts. Both the block of ice and the lake have a temperature of 0° C. If L represents the heat of fusion, the minimum distance the ice fell before striking the surface is

(A) $\frac{L}{5g}$

(B) $\frac{5L}{g}$

(C) $\frac{gL}{5m}$

(D) $\frac{\text{mL}}{5\text{g}}$

EH0057

20. The specific heat of a metal at low temperatures varies according to $S = aT^3$ where a is a constant and T is the absolute temperature. The heat energy needed to raise unit mass of the metal from T = 1 K to T = 2 K is:-

(A) 3 a

(B) $\frac{15a}{4}$

(C) $\frac{2a}{3}$

(D) $\frac{12 \, a}{5}$

EH0058

2 kg ice at - 20°C is mixed with 5 kg water at 20°C. Then final amount of water in the mixture would be; Given specific heat of ice = 0.5cal/g°C, specific heat of water = 1 cal/g°C, Latent heat of fusion of ice = 80 cal/g.
 [JEE' (Scr) 2003]

(A) 6 kg

(B) 5 kg

(C) 4 kg

(D) 2 kg

EH0061

22. Some steam at 100°C is passed into 1.1 kg of water contained in a calorimeter of water equivalent 0.02 kg at 15°C so that the temperature of the calorimeter and its contents rises to 80°C. What is the mass of steam condensing. (in kg)

(A) 0.130

(B) 0.065

(C) 0.260

(D) 0.135

EH0062

23. Find the amount of heat supplied to decrease the volume of an ice water mixture by 1 cm³ without any change in temperature. ($\rho_{ice} = 0.9 \ \rho_{water}$, $L_{ice} = 80 \ cal/gm$).

(A) 360 cal

(B) 500 cal

(C) 720 cal

(D) none of these

EH0063

A thermally insulated vessel contains some water at 0°C. The vessel is connected to a vacuum pump 24. to pump out water vapour. This results in some water getting frozen. It is given Latent heat of vaporization of water at 0° C = 21 × 10^{5} J/kg and latent heat of freezing of water = 3.36×10^{5} J/kg. The maximum percentage amount of water that will be solidified in this manner will be :-

(A) 86.2%

(B) 33.6%

(C) 21%

(D) 24.36%

EH0108

Thermal expansion:

A thin copper wire of length L increase in length by 1% when heated from temperature T_1 to T_2 . What is the percentage change in area when a thin copper plate having dimensions $2L \times L$ is heated from T_1 to T_2 ?

(A) 1%

(B) 2%

(C) 3%

(D) 4%

EH0069

A hole is made in a metal plate, when the temperature of metal is raised then the diameter of the hole **26.** will:-

- (A) Decrease
- (B) Increase
- (C) Remain same
- (D) Answer depends upon the initial temperature of the metal

EH0065

27. The radius of a metal sphere at room temperature T is R, and the coefficient of linear expansion of the metal is α . The sphere is heated a little by a temperature ΔT so that its new temperature is $T + \Delta T$. The increase in the volume of the sphere is approximately

(A) $2\pi R \propto \Delta T$

(B) $\pi R^2 \propto \Delta T$

(C) $4\pi R^3 \propto \Delta T/3$

(D) $4\pi R^3 \propto \Delta T$

EH0064

28. Two rods one of aluminium of length l_1 having coefficient of linear expansion α_a , and other steel of length l_2 having coefficient of linear expansion α_s are joined end to end. The expansion in both the

rods is same on variation of temperature. Then the value of $\frac{l_1}{l_1 + l_2}$ is [JEE' (Scr) 2003]

(A) $\frac{\alpha_s}{\alpha_a + \alpha_s}$ (B) $\frac{\alpha_s}{\alpha_a - \alpha_s}$ (C) $\frac{\alpha_a + \alpha_s}{\alpha_s}$

(D) None of these

EH0072

A steel tape gives correct measurement at 20°C. A piece of wood is being measured with the steel 29. tape at 0°C. The reading is 25 cm on the tape, the real length of the given piece of wood must be:

(A) 25 cm

(B) < 25 cm

(C) > 25 cm

(D) can not say

EH0067

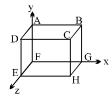
- **30.** The coefficient of apparent expansion of a liquid in a copper vessel is C and in a silver vessel is S. The coefficient of volume expansion of copper is γ_c . What is the coefficient of linear expansion of silver?
 - $(A) \; \frac{(C+\gamma_c+S)}{3}$
- (B) $\frac{(C \gamma_c + S)}{3}$ (C) $\frac{(C + \gamma_c S)}{3}$ (D) $\frac{(C \gamma_c S)}{3}$

EH0071

- 31. An open vessel is filled completely with oil which has same coefficient of volume expansion as that of the vessel. On heating both oil and vessel,
 - (A) the vessel can contain more volume and more mass of oil
 - (B) the vessel can contain same volume and same mass of oil
 - (C) the vessel can contain same volume but more mass of oil
 - (D) the vessel can contain more volume but same mass of oil

EH0073

A cuboid ABCDEFGH is anisotropic with $\alpha_x = 1 \times 10^{-5}$ /°C, $\alpha_y = 2 \times 10^{-5}$ /°C, $\alpha_z = 3 \times 10^{-5}$ /°C. **32.** Coefficient of superficial expansion of faces can be



(A)
$$\beta_{ABCD} = 5 \times 10^{-5} \, / ^{\circ} \text{C}$$

(B)
$$\beta_{BCGH} = 4 \times 10^{-5} \, / ^{\circ}C$$

(C)
$$\beta_{CDEH} = 3 \times 10^{-5} / {^{\circ}C}$$

(D)
$$\beta_{EFGH} = 2 \times 10^{-5} / ^{\circ}C$$

EH0070

- A rod of length 2m rests on smooth horizontal floor. If the rod is heated from 0°C to 20°C. Find the 33. longitudinal strain developed? ($\alpha = 5 \times 10^{-5}$ /°C)
 - (A) 10^{-3}
- (B) 2×10^{-3}
- (C) Zero
- (D) None

EH0066

- The bulk modulus of copper is 1.4×10^{11} Pa and the coefficient of linear expansion is 34. 1.7×10^{-5} (C°)⁻¹. What hydrostatic pressure is necessary to prevent a copper block from expanding when its temperature is increased from 20°C to 30°C?
 - (A) $6.0 \times 10^5 \,\text{Pa}$
- (B) $7.1 \times 10^7 \text{ Pa}$
- (C) $5.2 \times 10^6 \text{ Pa}$
- (D) 40 atm

EH0068

- A rod of length 2m at 0°C and having expansion coefficient $\alpha = (3x + 2) \times 10^{-6}$ °C⁻¹ where x is the **35.** distance (in cm) from one end of rod. The length of rod at 20°C is:
 - (A) 2.124 m
- (B) 3.24 m
- (C) 2.0120 m
- (D) 3.124 m

EH0113

The transfer of heat from one body to another may take place by any one of the following modes:.

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 and 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.

Conduction	Convection	Radiation	
Heat Transfer due to Temperature difference	Heat transfer due to density difference	Heat transfer with out any medium	
Due to free electron or vibration motion of molecules	Actual motion of particles	Electromagnetic radiation	
Heat transfer in solid body (in mercury also)	Heat transfer in fluids (Liquid + gas)	All	
Slow process	Slow process	Fast process (3 \times 10 8 m/sec)	
Irregular path	Irregular path	Straight line (like light)	

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.

Steady state: When temperature of the each cross–section of the bar becomes constant through different for different cross–sections is called steady state.

• Equation of thermal conduction

Rate of heat flow
$$\frac{dQ}{dt} = -KA\frac{d\theta}{dx}$$
 $\frac{dQ}{dt} = \frac{KA}{L}(\theta_1 - \theta_2)$

Cross section area = A; Length = L

Thermal conductivity of material = K

$\theta_1 \text{ hot} \qquad \text{cold } \theta_2$ $\theta \cdot dx \quad \theta + d\theta$ flow of heat $\theta \cdot dx \quad \theta + d\theta$ flow of heat $\theta \cdot dx \quad \theta + d\theta$ flow of heat

• Thermal (temperature) gradient

The decrease in temperature with distance from hot end of the rod is known as temperature gradient or in the direction of heat energy flow, the rate of fall in temperature w.r.t. distance is called as temperature gradient. It is denoted by –dT/dx

- Thermal conductivity (K): It's depends on nature of material.
 - SI UNIT: $J s^{-1} m^{-1} K^{-1}$ Dimensions: $M^1 L^1 T^{-3} \theta^{-1} K$ For Ag maximum is (410 W/mK)
 For Freon minimum is 12 (0.008 W/mK)
 - For an ideal or perfect conductor of heat the value of $K = \infty$
 - For an ideal or perfect bad conductor or insulator the value of K = 0
 - For cooking the food, low specific heat and high conductivity utensils are 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 and fur coat.
- Two thin blankets are warmer than a single blanket of double the thickness.
- Birds often swell their feathers in winter.
- A new quilt is warmer than old one.

THERMAL RESISTANCE (R)

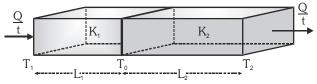
The thermal resistance of a body is a measure of its opposition of the flow of heat through it. $R = \frac{L}{KA}$

Heat flow through slabs in series

$$R_{eq} = R_1 + R_2$$

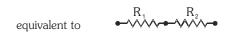
$$L_1 + L_2 \qquad L_1$$

$$\frac{L_1 + L_2}{K_{eq}A} = \frac{L_1}{K_1A} + \frac{L_2}{K_2A}$$



Equivalent thermal conductivity of the system is

$$K_{eq} = \frac{L_1 + L_2}{\frac{L_1}{K_1} + \frac{L_2}{K_2}} = \frac{\Sigma L_i}{\Sigma \frac{L_i}{K_i}}$$

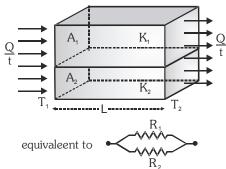


• Heat flow through slabs in parallel

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}, R = \frac{L}{KA}; \frac{K_{eq}}{L}(A_1 + A_2) = \frac{K_1A_1}{L} + \frac{K_2A_2}{L}$$

Equivalent thermal conductivity

$$\label{eq:Keq} K_{eq} = \frac{K_1 A_1 + K_2 A_2}{A_1 + A_2} \; = \; \frac{\Sigma K_i A_i}{\Sigma A_i}$$



GROWTH OF ICE ON LAKES

In winter atmospheric temperature falls below 0° C and water in the lake start freezing. Let at time t thickness of ice on the surface of the lake = x and air temperature = $-\theta^{\circ}$ C

The temperature of water in contact with the lower surface of ice = 0° C

Let area of the lake = A

air at 0° C

Heat escaping through ice in time dt is

$$dQ = KA \frac{[0 - (-\theta)]}{x} dt$$

Due to escape of this heat increasing extra thickness of ice = dx

Mass of this extra thickness of ice is $m = \rho V = \rho A.dx$

$$dQ = mL = (\rho A.dx) L$$

$$\therefore KA \frac{\theta}{x} dt = (\rho A.dx) L \qquad \Rightarrow dt = \frac{\rho L}{K\theta} x dx$$

$$\Rightarrow$$
 dt = $\frac{\rho L}{K \theta} x dx$

So time taken by ice to grow a thickness x is $t = \frac{\rho L}{\kappa \Omega} \int_0^x x dx = \frac{1}{2} \frac{\rho L}{\kappa \Omega} x^2$ So time taken by ice to grow from thickness x_1 to thickness x_2 is

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

Time taken to double and triple the thickness ratio $t_1: t_2: t_3:: 1^2: 2^2: 3^2$

So
$$t_1: t_2: t_3:: 1:4:9$$

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 $K = 0.26 \text{ cal s}^{-1} \text{ cm}^{-1} \, ^{\circ}\text{C}^{-1}$.

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

Sol.
$$\frac{Q}{r} = 0.5 \text{ cal s}^{-1}$$
; $r = 1 \text{ cm}$ \therefore Area $A = \pi r^2 = 3.142 \times 1 \text{ cm}^2 = 3.142 \text{ cm}^2$

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 $(T_1 - T_2) = \frac{Q}{t} \times \frac{\Delta x}{kA} = \frac{0.5 \times 200}{0.26 C^{-1} \times 3.142} = 122.4 ^{\circ}C$

$$T_2 = 250^{\circ}\text{C} - 122.4^{\circ}\text{C} = 127.6^{\circ}\text{C}$$

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 temp. 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) = $2\pi \times 0.1 \times 2 = 0.4 \text{ mm}^2$

 $K = 390 \text{ W m}^{-1} \text{ K}^{-1}$

$$T_1 = 373 \text{ K}, T_2 = 0^{\circ}\text{C} = 273 \text{ K}, \qquad L = 5 \text{ mm} = 0.005 \text{ m}$$

$$L = 5 \text{ mm} = 0.005 \text{ m}$$
 and $t = 1$

$$\therefore Q = \frac{390 \times 0.4 \pi \times (373 - 273) \times 1}{0.005} = \frac{390 \times 0.4 \pi \times 100}{0.005} = 98 \times 10^5 \text{ J}.$$

36

- **Ex.** 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.

Hence, $\frac{K}{L}$ remain constant. If K_1 and K_2 be the thermal conductivities of brick and cement respectively

and L_1 and L_2 be the required thickness then $\frac{K_1}{L_1} = \frac{K_2}{L_2}$ or $\frac{1.7}{20} = \frac{2.9}{L_2}$

$$\therefore L_2 = \frac{2.9}{17} \times 20 = 34.12 \text{ cm}$$

- **Ex.** 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 identical, so A and x in both the cases is same.

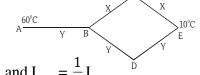
Now,
$$Q = \frac{K_1 A(\theta_1 - \theta_2)t_1}{L} = \frac{K_2 A(\theta_1 - \theta_2)t_2}{L} \Rightarrow \frac{K_1}{K_2} = \frac{t_2}{t_1} = \frac{25 \text{ min}}{10 \text{ min}} = \frac{5}{2}$$

Ex. Three rods of material X and three rods of material Y are connected as shown in figure. All the rods are identical in length and cross–sectional area. If the end A is maintained at 60°C and the junction E at at 10°C, calculate the temp. of the junctions B,C,D. The thermal conductivity of X is 0.92 CGS units and that of Y is 0.46 CGS units.

Sol.
$$R_x \propto \frac{1}{K_y}$$
, $R_y \propto \frac{1}{K_y} \Rightarrow \frac{R_x}{R_y} = \frac{K_y}{K_x} = \frac{0.46}{0.92} = \frac{1}{2}$ Let $R_x = R : R_y = 2R$

The total resistance $\Sigma R = R_y + \text{effective resistance}$ in the bridge

$$\Sigma R = 2R + \frac{2R \times 4R}{2R + 4R} = 2R + \frac{4}{3} R = \frac{10}{3} R \& : \Delta \theta = \ell \times R$$



Further

$$I_{BCE}(2R) = I_{BDE}(4R) \text{ and } I_{BCE} + I_{BDE} = I \Rightarrow I_{BCE} = \frac{2}{3}I \text{ and } I_{BDE} = \frac{1}{3}I$$

 $\theta_A - \theta_B = 60^0 - \theta_B \Rightarrow 60 - \theta_B = 2R \times I$...(i)

For A and B

For B and C

$$\theta_{\rm B} - \theta_{\rm C} = \frac{2}{3} (I \times R)$$
(ii) $\theta_{\rm C} - \theta_{\rm E} = \frac{2}{3} \times R \times I$

For A and E

$$\theta_{A} - \theta_{E} = 60 - 10 = 50 \implies \frac{10}{3} (R \times I) = 50 \dots (iii) \therefore R \times I = 15$$

$$\therefore \ \theta_{\text{A}} - \theta_{\text{B}} - 2 \times 15 = 30 \ , \ \theta_{\text{B}} = 60 - 30 \ = 30^{\circ} C \ , \ \theta_{\text{B}} - \theta_{\text{C}} = \left(\frac{2}{3}\right) \times 15 = 10$$

$$\therefore$$
 $\theta_C = 30 - 10 = 20^{\circ}C$ Obviously, $\theta_C = \theta_D = 20^{\circ}C$

Ex. 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.

2cm

- **Sol.** Rate of flow of heat in the plates is $\frac{Q}{t} = \frac{K_1 A(\theta_1 \theta)}{L_1} = \frac{K_2 A(\theta \theta_2)}{L_2}...(i)$
 - Here $\theta_1 = -20^{\circ}\text{C}$, $\theta_2 = 20^{\circ}\text{C}$, $L_1 = 2 \text{ cm} = 0.02 \text{ m}$, $L_2 = 5 \text{ cm} = 0.05 \text{ m}$ and $K_1 = K_2 = K$
 - ∴ equation (i) becomes $\frac{\text{KA}(-20-\theta)}{0.02} = \frac{\text{KA}(\theta-20)}{0.05}$ -20°C ∴ $5(-20-\theta) = 2(\theta-20) \Rightarrow -100 - 5\theta = 2\theta - 40 \Rightarrow 7\theta = -60 \Rightarrow \theta = -8.6^{\circ}\text{C}$

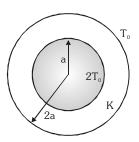


5cm

- ii) $\frac{K_1}{K_2} = \frac{2}{5} \text{ or } K_1 = \frac{2}{5} K_2$
 - $\therefore \text{ from equation (i) } \frac{2/5 \, K_2 A \left(-20 \theta\right)}{0.02} = \frac{K_2 A \left(\theta 20\right)}{0.05} 20 \theta = \theta 20 \text{ or } -2\theta = 0 \ \therefore \theta = 0^{\circ} C$
- Ex. An ice box used for keeping eatables cold has a total wall area of 1 metre² and a wall thickness of 5.0cm. The thermal conductivity of the ice box is K = 0.01 joule/metre-°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 jule/kg. Calculate the amount of ice melted in one day.
- **Sol.** $\frac{dQ}{dt} = \frac{KA}{L} d\theta = \frac{0.01 \times 1}{0.05} \times 30 = 6 \text{ joule/s}$ So $\frac{dQ}{dt} \times 86400 = 6 \times 86400$

Q = mL (L-latent heat),
$$m = \frac{Q}{L} = \frac{6 \times 86400}{334 \times 10^3} = 1.552 \text{ kg}$$

Ex. A hollow spherical ball of inner radius a and outer radius 2a is made of a uniform material of constant thermal conductivity K. The temperature within the ball is maintained at $2T_0$ and outside the ball it is T_0 . Find, (a) the rate at which heat flows out of the ball in the steady state, (b) the temperature at r = 3a/2, where r is radial distance from the centre of shell. Assume steady state condition.



Sol. In the steady state, the net outward thermal current is constant, and does not depend on the radial position.

$$Thermal \ current, C_{_1} = \left(\frac{dQ}{dt}\right) = -K. \left(4\pi r^2\right) \frac{dT}{dr} \Longrightarrow \frac{dT}{dr} = -\frac{C_{_1}}{4\pi K} \frac{1}{r^2} + C_{_2}$$

At r=a, T =
$$2T_0$$
 and r = $2a$, T= $T_0 \Rightarrow T = \frac{2a}{r}T_0$ (a) $\frac{dQ}{dt} = 8\pi a KT_0$ (b) $T(r = 3a/2) = 4T_0/3$

Thermal Radiation

The process of the transfer of heat from one place to another place without heating the intervening medium is called radiation. When a body is heated and placed in vacuum, it loses heat even when there is no medium surrounding it. The heat can not go out from the body by the process of conduction or convection since both of these process require the presence of a material medium between source and surrounding objects. The process by which heat is lost in this case is called radiation. This does not require the presence of any material medium.

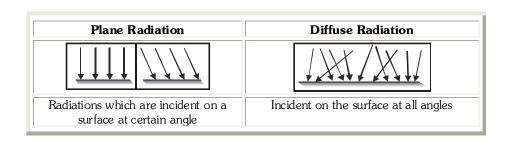
It is by radiation that the heat from the Sun reaches the Earth. Radiation has the following properties:

- (a) Radiant energy travels in straight lines and when some object is placed in the path, it's shadow is formed at the direction.
- (b) It can travel through vacuum.
- (c) Intensity of radiation follows the law of inverse square.
- (d) Thermal radiation can be polarised in the same way as light by transmission through a nicol prism.

38

All these and many other properties establish that heat radiation has nearly all the properties possessed by light and these are also electromagnetic waves with the only difference of wavelength or frequency. The wavelength of heat radiation is larger than that of visible light.

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



- When radiation passes through any medium then radiations slightly absorbed by medium according to its absorptive power so temperature of medium slightly increases.
- Heat radiation are always obtained in infra—red region of electromagnetic wave spectrum so they are called Infra red rays.

BASIC FUNDAMENTAL DEFINITIONS

• Energy Density (u)

The radiation energy of whole wavelength (0 to ∞) present in unit volume at any point in space is defined as energy density. **S I UNIT**: J/m³

• Spectral energy density (\mathbf{u}_{λ}) : Energy density per unit spectral region. $\mathbf{u} = \int_{0}^{\infty} \mathbf{u}_{\lambda} d\lambda$

• Absorptive power or absorptive coefficient 'a': 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

$$a = \frac{Q_a}{Q}$$
. It is unitless

• **Spectral absorptive power** (\mathbf{a}_{λ}) $\mathbf{a}_{\lambda} = \frac{\mathbf{Q}\mathbf{a}_{\lambda}}{\mathbf{Q}_{\lambda}}$: Also called monochromatic absorptive coefficient

At a given wavelength $a = \int_{0}^{\infty} a_{\lambda} d\lambda$. For ideal black body a_{λ} and a = 1, a and a_{λ} are unitless

- **Emissive power (e)**: The amount of heat radiation emitted by unit area of the surface in one second at a particular temperature. **SI UNIT**: J/m²s
- **Spectral Emmisive power** (e_{λ}) : 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 $e = \int_{0}^{\infty} e_{\lambda} d\lambda$

SI UNIT: W/m² Å

EMISSIVITY (e)

Absolute emissivity or emissivity: Radiation energy given out by a unit surface area of a body in unit time corresponding to unit temperature difference w.r.t. the surroundings is called Emissivity.

SIUNIT: W/m² °K

Relative emissivity ($\mathbf{e}_{\mathbf{r}}$): $\mathbf{e}_{\mathbf{r}} = \frac{Q_{GB}}{Q_{IBB}} = \frac{e_{GB}}{E_{IBB}} = \frac{\text{emitted radiation by gray body}}{\text{emitted radiation by ideal black body}}$

GB = gray or general body, IBB = Ideal black body

- (i) No unit
- (ii) For ideal black body $e_r = 1$
- (iii) range $0 < e_r < 1$

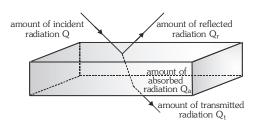
SPECTRAL, EMISSIVE, ABSORPTIVE AND TRANSMITTIVE POWER OF A GIVEN BODY SURFACE

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

$$Q = Q_r + Q_a + Q_t \Rightarrow \frac{Q_r}{Q} + \frac{Q_a}{Q} + \frac{Q_t}{Q} = 1 \Rightarrow r + a + t = 1$$

Reflective Coefficient $r = \frac{Q_r}{Q}$, Absorptive Coefficient $a = \frac{Q_a}{Q}$,



Transmittive Coefficient $t = \frac{Q_t}{Q}$

r = 1 and a = 0, t = 0Perfect reflector

a = 1 and r = 0, t = 0 \Rightarrow Ideal absorber (ideal absorber) and t = 1 and t = 0, t = 0 \Rightarrow Perfect transmitter Ideal absorber (ideal black body)

Reflection power (r) = $\left[\frac{Q_r}{Q} \times 100\right]$ %, Absorption power (a) = $\left[\frac{Q_a}{Q} \times 100\right]$ %

Transmission power (t) = $\left[\frac{Q_t}{Q} \times 100\right]$ %

Total radiations incident on body = $400 \,\mathrm{J}$, 20% radiation reflected and $120 \,\mathrm{J}$ absorbs. Then find out % Ex. of transmittive power

Sol. $Q = Q_t + Q_r + Q_s \Rightarrow 400 = 80 + 120 + Q_t \Rightarrow Q_t = 200$. So % of transmittive power is 50%

IDEAL BLACK BODY

- For a body surface which absorbs all incident thermal radiations 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 $a = a_{\lambda} = 1$ and r = 0 = t, $e_{r} = 1$
- The nature of emitted radiations from surface of ideal black body only depends on its temperature
- The radiations emitted from surface of ideal black body called as either full or white radiations.
- At low temperature surface of ideal black body 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)

1/10.10.100.245/DTPDat/node06/2020-21(80806A)/Kots/EEAAAnaed/Woddle Coding(V-Tag)/Leader/Mysias/Them of Mysias/English/02_Heathrans for pos

PREVOST'S THEORY OF HEAT ENERGY EXCHANGE

According to Prevost at every possible temperature (Not absolute 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.

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.

- 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.
- 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 (e₃) to spectral absorptive power (a_n) is constant and this constant is equal to spectral emissive power (E_n) of the ideal black body at same temperature

$$\frac{e_{\lambda}}{a_{\lambda}} = E_{\lambda} = \text{constant}$$
 $\left[\frac{e_{\lambda}}{a_{\lambda}}\right]_{1} = \left[\frac{e_{\lambda}}{a_{\lambda}}\right]_{2} = \text{constant } e_{\lambda} \propto a_{\lambda}$

Good absorbers are good emitters and bad absorbers are bad emitters

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

Good absorber Good emitter \rightleftharpoons Bad emitter Bad absorber \rightleftharpoons

(at Low temperature) (at high temperature)

APPLICATIONS OF KIRCHOFF LAW

In deserts days are hot and nights cold

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.



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.

Amount of radiation emitted $E \propto T^4$ where T = temperature of ideal black body (in K)

$$E = \sigma T^4$$
 This law is true for only ideal black body

SI Unit : E = watt/m²
$$\sigma$$
 = Stefen's constant = 5.67 x10⁻⁸ watt /m² K⁴

Dimensions of
$$\sigma : M^1L^0 T^{-3} \theta^{-4}$$

Total radiation energy emitted out by surface of area A in time t: If T is constant.

Ideal black body
$$Q_{IBB} = \sigma A T^4 t$$
 and for any other body $Q_{GB} = e_r \sigma A T^4 t$

Rate of emission of radiation

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

Rate of emission of radiation from ideal black body surface $E_1 = \sigma T^4$

Rate of absorption of radiation from surrounding $E_2 = \sigma T_0^4$

Net rate of loss of radiation from ideal black body surface is $E = E_1 - E_2 = \sigma T^4 - \sigma T_0^4 = \sigma (T^4 - T_0^4)$

Net loss of radiation energy from entire surface area in time t is $Q_{IBB} = \sigma A (T^4 - T_0^4) t$

For any other body $Q_{GB} = e_r A\sigma (T^4 - T_0^4) t$

If in time dt the net heat energy loss for ideal black body is dQ and because of this its temperature falls by $d\theta$

Rate of loss of heat
$$R_H = \frac{dQ}{dt} = \sigma A(T^4 - T_0^4)$$

It is also equal to emitted power or radiation emitted per second

Rate of fall in temperature (Rate of cooling)
$$R_F = \frac{d\theta}{dt} = \frac{\sigma A}{msJ} (T^4 - T_0^4) \left[\because \frac{dQ}{dt} = msJ \frac{d\theta}{dt} \right]$$

Note:

- (i) If all of T, T_0 , m, s, V, ρ , are same for different shape body then R_F and 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, $R_F \propto \frac{1}{s} \propto \frac{d\theta}{dt}$ so dt $\propto s$. If condition in specific heat is $\Rightarrow s_1 > s_2 > s_3$

If all cooled same temperature i.e. temperature fall is also identical for all then required time $t \propto s :: t_1 > t_2 > t_3$

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

- (i) Nature of radiating surface: greater the emissivity (e_.), faster will be the cooling.
- (ii) Area of radiating surface: greater the area of radiating surface, faster will be the cooling.
- (iii) Mass of radiating body: greater the mass of radiating body slower will be the cooling.
- (iv) Specific heat of radiating body: greater the specific heat of radiating body slower will be the cooling.
- (v) Temperature of radiating body: greater the temperature of radiating body faster will be the cooling.

1/10.10.100.245/DPPDab Inode06/2020-21(B080-B4) Worb\EEEAdraneed\Waddle Cading IV-Tag\\Leader\Riysis\Themal Rhysis\Teglish\02_Heartranshr.p65



Sol.
$$\therefore$$
 Rate of emission = wattage of the lamp

$$\therefore W = Ae\sigma T^4 \Rightarrow A = \frac{W}{e\sigma T^4} = \frac{25}{0.3 \times 5.67 \times 10^{-8} \times (200)^4} = 0.918 \text{ m}^2$$

NEWTON'S LAW OF COOLING

Rate of loss of heat $\left(\frac{dQ}{dt}\right)$ is directly proportional to excess of temperature of the body over that of

surrounding. [(when
$$(\theta - \theta_0) \ge 35^{\circ}$$
C] $\frac{dQ}{dt} \propto (\theta - \theta_0)$ $\Rightarrow \frac{dQ}{dt} = \text{ms} \frac{d\theta}{dt}$

 θ = temperature of body [in °C], θ_0 = temperature of surrounding, $\theta - \theta_0$ = excess of temperature ($\theta > \theta_0$)

If the temperature of body decrease $d\theta$ in time dt then rate of fall of temperature $-\frac{d\theta}{dt} \propto (\theta - \theta_0)$

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

Excess of temperature

If the temperature of body decreases from θ_1 to θ_2 and temperature of surroundings is θ_0 then

average excess of temperature =
$$\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$$
 $\Rightarrow \left[\frac{\theta_1 - \theta_2}{t}\right] = -K\left[\frac{\theta_1 + \theta_2}{2} - \theta_0\right]$

Ex. If a liquid takes 30 seconds in cooling of 80°C to 70°C and 70 seconds in cooling 60°C to 50°C, then find the room temperature.

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

In first case,
$$\frac{80-70}{30} = K \left(\frac{80+70}{2} - \theta_0 \right)$$
 $\frac{1}{3} = K (75 - \theta_0) ...(i)$

In second case,
$$\frac{60-50}{70} = K \left(\frac{60+50}{2} - \theta_0 \right) \frac{1}{7} = K (55 - \theta_0) \dots (ii)$$

Equation (i) divide by equation (ii)
$$\frac{7}{3} = \frac{(75 - \theta_0)}{(55 - \theta_0)} \Rightarrow 385 - 7\theta_0 = 225 - 3\theta_0 \Rightarrow \theta_0 = \frac{160}{4} = 40^{\circ}\text{C}$$

Limitations of Newton's Law

- Temperature difference should not exceed 35° C, $(\theta \theta_0) \ge 35^\circ$ C
- Loss of heat should only be by radiation.
- This law is an extended form of Stefan–Boltzman's law.

For Heating, Newton's law of heating $\frac{\theta_1 - \theta_2}{t} = +H \left[\theta_0 - \frac{\theta_1 + \theta_2}{2} \right]$ H heating constant.

Derivation of Newton's law from Steafen's Boltzman law

$$\frac{d\theta}{dt} = \frac{\sigma A}{msJ} (T^4 - T_0^4) \qquad \qquad \begin{cases} T - T_0 = \Delta T \\ T = T_0 + \Delta T \end{cases}$$

$$\frac{d\theta}{dt} = \frac{\sigma A}{msJ} (T^4 - {T_0}^4) \qquad \qquad T - T_0 = \Delta T \text{ , } \Delta T <<< T_0$$

$$\frac{d\theta}{dt} = \frac{\sigma A}{msJ} \left[(T_0 + \Delta T)^4 - T_0^4 \right]$$
 If $x \ll 1$ then $(1 + x)^n = 1 + nx$

$$dt = msJ \begin{bmatrix} r_0 \\ r_1 \end{bmatrix}$$

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

$$\frac{d\theta}{dt} = \left[4 \frac{\sigma A}{msJ} T_0^3 \right] \Delta T \Longrightarrow \frac{d\theta}{dt} = K \Delta T \qquad constant \ K = \frac{4\sigma A T_0^3}{msJ}$$

constant
$$K = \frac{4\sigma A T_0^3}{msJ}$$

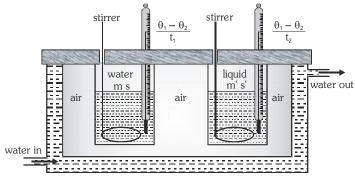
Newton's law of cooling

 $\frac{d\theta}{dt} \propto \Delta T$ (for small temperature difference)

APPLICATION OF NEWTON'S LAW OF COOLING

To find out specific heat of a given liquid

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.



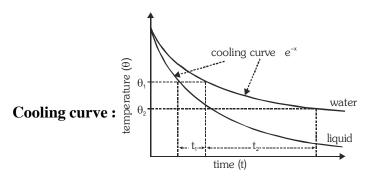
fall of temperature from $\theta_1 \to \theta_2$ in time t_1 for water and t_2 for liquid

$$\therefore \left[\frac{dQ}{dt} \right]_{Water} = \left[\frac{dQ}{dt} \right]_{Liquis}$$

$$\therefore \left[\frac{dQ}{dt} \right]_{\text{Water}} = \left[\frac{dQ}{dt} \right]_{\text{Liquid}} \quad \therefore \quad (ms+w) \left[\frac{\theta_1 - \theta_2}{t_1} \right] = (m's' + w) \left[\frac{\theta_1 - \theta_2}{t_2} \right] \qquad \Rightarrow \frac{ms + w}{t_1} = \frac{m's' + w}{t_2}$$

$$\Rightarrow \frac{ms+w}{t_1} = \frac{m's'+w}{t_2}$$

where w = water equivalent of calorimeter.



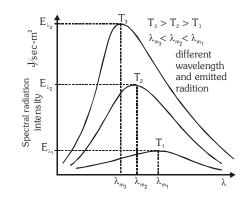
- When a calorimeter contains 40g of water at 50°C, then the temperature falls to 45°C in 10 minutes. Ex. The same calorimeter contains 100g of water at 50°C, it takes 20 minutes for the temperature to become 45°C. Find the water equivalent of the calorimeter.
- $\frac{m_1s_1 + W}{t_1} = \frac{m_2s_2 + W}{t_2}$ where W is the water equivalent

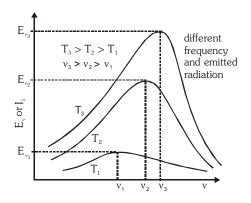
$$\Rightarrow \frac{40 \times 1 + W}{10} = \frac{100 \times 1 + W}{20} \Rightarrow 80 + 2W = 100 + W \Rightarrow W = 20 \text{ g}$$

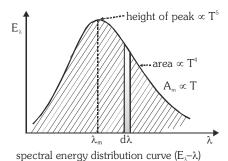
SPECTRAL ENERGY DISTRIBUTION CURVE OF BLACK BODY RADIATIONS

Practically given by: Lumers and Pringshem

Mathematically given by: Plank







- (i) $\lambda_{\rm m} \propto \frac{1}{T}$
- (ii) $E_{\lambda_m} \propto T^5$

(iii) Area
$$\int_{0}^{\infty} E_{\lambda} d\lambda = E = \sigma T^{4} \frac{A_{1}}{A_{2}} = \left[\frac{T_{1}}{T_{2}}\right]^{4}$$

- Spectral energy distribution curves are continuous. At any temperature in between possible wavelength $(0-\infty)$ radiation emitted but for different wavelength quantity of radiations are different.
- As the wave length increases, the amount of radiation emitted first increase, becomes maximum and then decreases.
- At a particular temperature the area enclosed between the spectral energy curve shows the spectral emissive power of the body. Area = $\int_{0}^{\infty} E_{\lambda} d\lambda = E = \sigma T^{4}$

WEIN'S DISPLACEMENT LAW

The wavelength corresponding to maximum emission of radiation decrease with increasing temperature $\left[\lambda_m \propto \frac{1}{T}\right]$. This is known as Wein's displacement law. $\lambda_m T = b$ where b Wein's constant $= 2.89 \times 10^{-3}$ mK.

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

Relation between frequency and temperature $v_m = \frac{c}{b}T$

ALLEN

Ex. The temperature of furnace is 2000°C, in its spectrum the maximum intensity is obtained at about 4000Å, If the maximum intensity is at 2000Å calculate the temperature of the furnace in °C.

Sol. by using
$$\lambda_m T = b$$
, 4000 (2000+273) = 2000(T) $\Rightarrow T = 4546K$

The temperature of furnace = 4546 - 273 = 4273 °C

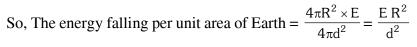
SOLAR CONSTANT 'S'

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/m² or 1.937 Cal/cm²-minute

• 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. The total energy emitted by the Sun in one second = E.A = E × $4\pi R^2$. (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 $4\pi d^2$)



$$R = 7 \times 10^8 \text{m}$$
, $d = 1.5 \times 10^{11} \text{ m}$, $s = 5.7 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$

Solar constant
$$S = \frac{E R^2}{d^2}$$

By Stefan's Law
$$E = \sigma T^4$$

$$S = \frac{\sigma T^4 R^2}{d^2} \Rightarrow T = \left[\frac{S \times d^2}{\sigma \times R^2}\right]^{\frac{1}{4}} = \left[\frac{1340 \times (1.5 \times 10^{11})^2}{5.7 \times 10^{-8} \times (7 \times 10^8)^2}\right]^{\frac{1}{4}} = 5732 K$$

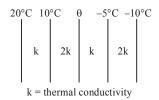
EXERCISE (S)

Conduction

1. A thin walled metal tank of surface area 5m² is filled with water and contains an immersion heater dissipating 1 kW. The tank is covered with 4 cm thick layer of insulation whose thermal conductivity is 0.2 W/m/K. The outer face of the insulation is 25°C. Find the temperature of the tank in the steady state

EH0018

2. The figure shows the face and interface temperature of a composite slab containing of four layers of two materials having identical thickness. Under steady state condition, find the value of temperature θ.

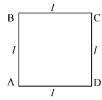


EH0019

3. Three conducting rods of same material and cross-section are shown in figure. Temperature of A, D and C are maintained at 20°C, 90°C and 0°C. Find the ratio of length BD and BC if there is no heat flow in AB.

EH0020

4. In the square frame of side l of metallic rods, the corners A and C are maintained at T_1 and T_2 respectively. The rate of heat flow from A to C is ω. If A and D are instead maintained $T_1 \& T_2$ respectively. Find the total rate of heat flow.



5. One end of copper rod of uniform cross-section and of length 1.5 meters is in contact with melting ice and the other end with boiling water. At what point along its length should a temperature of 200°C be maintained, so that in steady state, the mass of ice melting is equal to that of steam produced in the same interval of time? Assume that the whole system is insulated from the surroundings.

EH0022

Radiation

6. Two spheres of same radius R have their densities in the ratio 8:1 and the ratio of their specific heats are 1:4. If by radiation their rates of fall of temperature are same, then find the ratio of their rates of losing heat.

EH0023

7. A solid receives heat by radiation over its surface at the rate of 4 kW. The heat convection rate from the surface of solid to the surrounding is 5.2 kW, and heat is generated at a rate of 1.7 kW over the volume of the solid. The rate of change of the average temperature of the solid is 0.5°Cs⁻¹. Find the heat capacity of the solid.

EH0024

8. A solid copper cube and sphere, both of same mass & emissivity are heated to same initial temperature and kept under identical conditions. What is the ratio of their initial rate of fall of temperature?

EH0025

9. A vessel containing 100 gm water at 0°C is suspended in the middle of a room. In 15 minutes the temperature of the water rises by 2°C. When an equal amount of ice is placed in the vessel, it melts in 10 hours. Calculate the specific heat of fusion of ice.

EH0026

10. The maximum in the energy distribution spectrum of the sun is at 4753 Å and its temperature is 6050K. What will be the temperature of the star whose energy distribution shows a maximum at 9506Å.

EH0027

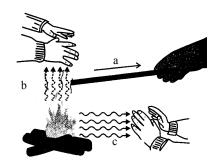
11. A pan filled with hot food cools from 50.1 °C to 49.9 °C in 5 sec. How long will it take to cool from 40.1 °C to 39.9 °C if room temperature is 30 °C?

EXERCISE (O)

SINGLE CORRECT TYPE QUESTIONS

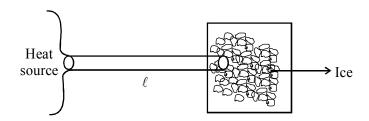
Conduction

- 1. Diagram shows a heat source 'S' and three position of heat recover (hand). The main made of heat transfer is given as 'a', 'b' & 'c'. Choose the correct matching:-
 - (A) a conduction; b convection; c radiation
 - (B) b conduction; a convection; c radiation
 - (C) a conduction; c convection; b radiation
 - (D) c conduction; b radiation; a convection

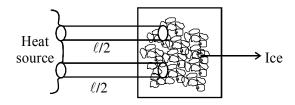


EH0074

2. A rod of length ℓ and cross-section 'A' is used to melt a piece of ice as shown.



Now if the rod broken into two equal parts and is arranged as shown.



Time taken to melt ice in second use becomes.

- (A) Half
- (B) One-forth
- (C) Twice
- (D) Four times

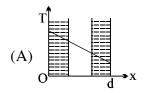
EH0075

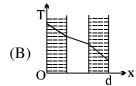
3. One end of a 2.35m long and 2.0cm radius aluminium rod ($K = 235 \text{ W.m}^{-1}K^{-1}$) is held at 20°C. The other end of the rod is in contact with a block of ice at its melting point. The rate in kg.s⁻¹ at which ice

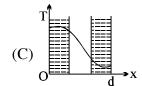
melts is [Take latent heat of fusion for ice as $\frac{10}{3} \times 10^5 \text{ J.kg}^{-1}$]

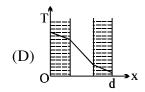
- (A) $48\pi \times 10^{-6}$
- (B) $24\pi \times 10^{-6}$
- (C) $2.4\pi \times 10^{-6}$
- (D) $4.8\pi \times 10^{-6}$

4. The wall with a cavity consists of two layers of brick separated by a layer of air. All three layers have the same thickness and the thermal conductivity of the brick is much greater than that of air. The left layer is at a higher temperature than the right layer and steady state condition exists. Which of the following graphs predicts correctly the variation of temperature T with distance d inside the cavity?









EH0077

5. A wall has two layer A and B each made of different material, both the layers have the same thickness. The thermal conductivity of the material A is twice that of B. Under thermal equilibrium the temperature difference across the wall B is 36°C. The temperature difference across the wall A is

(A) 6°C

(B) 12°C

(C) 18°C

(D) 72°C

EH0078

Two identical conducting rods are first connected independently to two vessels, one containing water at 100° C and the other containing ice at 0° C. In the second case, the rods are joined end to end and connected to the same vessels. Let q_1 and q_2 g/s be the rate of melting of ice in the two cases respectively. The ratio q_2/q_1 is [JEE' 2004 (Scr.)]

(A) 1/2

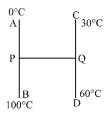
(B) 2/1

(C) 4/1

(D) 1/4

EH0079

7. Three identical rods AB, CD and PQ are joined as shown. P and Q are mid points of AB and CD respectively. Ends A, B, C and D are maintained at 0°C, 100°C, 30°C and 60°C respectively. The direction of heat flow in PQ is



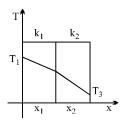
(A) from P to Q

(B) from Q to P

(C) heat does not flow in PQ

(D) data not sufficient

8. The temperature drop through each layer of a two layer furnace wall is shown in figure. Assume that the external temperature T_1 and T_3 are maintained constant and $T_1 > T_3$. If the thickness of the layers \mathbf{x}_1 and \mathbf{x}_2 are the same, which of the following statements are correct.



- (A) $k_1 > k_2$
- (B) $k_1 < k_2$
- (C) $k_1 = k_2$ but heat flow through material (1) is larger then through (2)
- (D) $k_1 = k_2$ but heat flow through material (1) is less than that through (2)

EH0081

9. A composite rod made of three rods of equal length and cross-section as shown in the fig. The thermal conductivities of the materials of the rods are K/2, 5K and K respectively. The end A and end B are at constant temperatures. All heat entering the end A goes out of the end B, there being no loss of heat from the sides of the bar. The effective thermal conductivity of the bar is



- (A) 15K/16
- (B) 6K/13
- (C) 5K/16
- (D) 2K/13.

EH0082

10. Figure shows three different arrangements of materials 1, 2 and 3 to form a wall. Thermal conductivities are $k_1 > k_2 > k_3$. The left side of the wall is 20°C higher than the right side. Temperature difference ΔT across the material 1 has following relation in three cases:



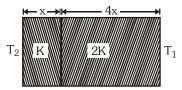


- (A) $\Delta T_a > \Delta T_b > \Delta T_c$
- (B) $\Delta T_a = \Delta T_b = \Delta T_c$ (C) $\Delta T_a = \Delta T_b > \Delta T_c$
- (D) $\Delta T_a = \Delta T_b < \Delta T_c$

EH0083

11. The temperature of the two outer surfaces of a composite slab, consisting of two materials having coefficients of thermal conductivity K and 2K and thickness x and 4x, respectively are T_2 and $T_1(T_2 > T_1)$. The rate of

heat transfer through the slab, in a steady state is $\left(\frac{A(T_2 - T_1)K}{x}\right)f$, with f



equals to-

[AIEEE - 2004]

(A) 1

- (B) 1/2
- (C) 2/3
- (D) 1/3

Radiation

- A black metal foil is warmed by radiation from a small sphere at temperature 'T' and at a distance 'd'. It is found that the power received by the foil is P. If both the temperature and distance are doubled, the power received by the foil will be:
 - (A) 16 P
- (B) 4 P
- (C) 2P
- (D) P

EH0085

- **13.** The rate of emission of radiation of a black body at 273°C is E, then the rate of emission of radiation of this body at 0°C will be :-
 - (A) $\frac{E}{16}$
- (B) $\frac{E}{4}$
- (C) $\frac{E}{8}$
- (D)0

EH0086

- The power radiated by a black body is P and it radiates maximum energy around the wavelength λ_0 . **14.** If the temperature of the black body is now changed so that it radiates maximum energy around wavelength $3/4\lambda_0$, the power radiated by it will increase by a factor of :-
 - (A) 4/3
- (B) 16/9
- (C) 64/27
- (D) 256/81

EH0087

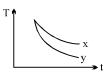
- **15.** Spheres P and Q are uniformly constructed from the same material which is a good conductor of heat and the radius of Q is thrice the radius of P. The rate of fall of temperature of P is x times that of Q when both are at the same surface temperature. The value of x is:
 - (A) 1/4
- (B) 1/3
- (C) 3
- (D) 4

EH0088

- 16. Two spheres of the same material have radii 1 m and 4 m and temperatures 4000 K and 2000 K respectively. The ratio of the energy radiated per second by the first sphere to that by the second is-
 - (A) 1:1
- (B) 16:1
- (C) 4:1
- (D) 1:9

EH0089

If emissivity of bodies X and Y are e_x and e_y and absorptive power are A_x and A_y then **17.** [JEE' (Scr) 2003]



(A) $e_y > e_x$; $A_y > A_x$

(B) $e_y < e_x$; $A_y < A_x$ (D) $e_y = e_x$; $A_y = A_x$

(C) $e_v > e_x$; $A_v < A_x$

EH0090

18. Three discs A, B, and C having radii 2 m, 4 m and 6 m respectively are coated with carbon black on their outer surfaces. The wavelengths corresponding to maximum intensity are 300 nm, 400 nm and 500 nm respectively. The power radiated by them are Q_A , Q_B and Q_C respectively.

[JEE' 2004 (Scr.)]

- (A) Q_A is maximum

- (B) Q_B is maximum (C) Q_C is maximum (D) $Q_A = Q_B = Q_C$

- 19. A black body calorimeter filled with hot water cools from 60°C to 50°C in 4 min and 40°C to 30°C in 8 min. The approximate temperature of surrounding is:
 - (A) 10° C
- $(B) 15^{\circ}C$
- (C) 20°C
- (D) 25°C

EH0092

- A system S receives heat continuously from an electrical heater of power 10W. The temperature of S 20. becomes constant at 50°C when the surrounding temperature is 20°C. After the heater is switched off, S cools from 35.1°C to 34.9°C in 1 minute. The heat capacity of S is
 - (A) 100J/°C
- (B) 300J/°C
- (C) 750J/°C
- (D) 1500J/°C

EH0093

- If the temperature of the sun were to increase from T to 2T and its radius from R to 2R, then the ratio 21. of the radiant energy received on earth to what it was previously, will be- [AIEEE - 2004]
 - (A)4

- (B) 16
- (C) 32
- (D) 64

EH0094

MULTIPLE CORRECT TYPE QUESTIONS

Radiation

- 22. Two metallic sphere A and B are made of same material and have got identical surface finish. The mass of sphere A is four times that of B. Both the spheres are heated to the same temperature and placed in a room having lower temperature but thermally insulated from each other.
 - (A) The ratio of heat loss of A to that of B is $2^{4/3}$.
 - (B) The ratio of heat loss of A to that of B is $2^{2/3}$.
 - (C) The ratio of the initial rate of cooling of A to that of B is $2^{-2/3}$.
 - (D) The ratio of the initial rate of cooling of A to that of B is $2^{-4/3}$.

EH0104

- 23. Two bodies A and B have thermal emissivities of 0.01 and 0.81 respectively. The outer surface areas of the two bodies are the same. The two bodies radiate energy at the same rate. The wavelength $\lambda_{\rm p}$, corresponding to the maximum spectral radiancy in the radiation from B, is shifted from the wavelength corresponding to the maximum spectral radiancy in the radiation from A by 1.00 µm. If the temperature of A is 5802 K,
 - (A) the temperature of B is 1934 K
- (B) $\lambda_{\rm B} = 1.5 \,\mu \rm m$
- (C) the temperature of B is 11604 K
- (D) the temperature of B is 2901 K

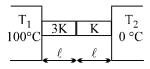
EH0105

COMPREHENSION TYPE QUESTIONS

Conduction

Paragraph for Question No. 24 to 26

Two rods A and B of same cross-sectional are A and length l connected in series between a source $(T_1 = 100^{\circ}C)$ and a sink $(T_2 = 0^{\circ}C)$ as shown in figure. The rod is laterally insulated



- 24. The ratio of the thermal resistance of the rods is
 - (A) $\frac{R_A}{R_B} = \frac{1}{3}$ (B) $\frac{R_A}{R_B} = 3$ (C) $\frac{R_A}{R_B} = \frac{3}{4}$ (D) $\frac{4}{3}$

EH0106

- If $\boldsymbol{T}_{\boldsymbol{A}}$ and $\boldsymbol{T}_{\boldsymbol{B}}$ are the temperature drops across the rod A and B, then
 - (A) $\frac{T_A}{T_B} = \frac{3}{1}$ (B) $\frac{T_A}{T_B} = \frac{1}{3}$ (C) $\frac{T_A}{T_B} = \frac{3}{4}$ (D) $\frac{T_A}{T_B} = \frac{4}{3}$

EH0106

- If G_A and G_B are the temperature gradients across the rod A and B, then
- (A) $\frac{G_A}{G_B} = \frac{3}{1}$ (B) $\frac{G_A}{G_B} = \frac{1}{3}$ (C) $\frac{G_A}{G_B} = \frac{3}{4}$ (D) $\frac{G_A}{G_B} = \frac{4}{3}$

EH0106

Ε

KINETIC THEORY OF GASES

The properties of the gases are entirely different from those of solid and liquid. In case of gases, thermal expansion is very large as compared to solids and liquids .To state the conditions of a gas, its volume, pressure and temperature must be specified.

Intermolecular force Solid > liquid > real gas > ideal gas (zero)

Potential energy Solid < liquid < real gas < ideal gas (zero)

Internal energy, internal kinetic energy, internal potential energy

At a given temperature for solid, liquid and gas:

- (i) Internal kinetic energy: Same for all
- (ii) Internal potential Energy: Maximum for ideal gas (PE = 0) and Minimum for solids (PE = -ve)
- (iii) Internal Energy: Maximum for Ideal gas and Minimum for solid

At a given temperature for rared and compressed gas:

- (i) Internal kinetic energy \rightarrow Same
- (ii) Internal potential energy \rightarrow (PE)_{Rared} > (PE)_{compressed}
- (iii) Internal Energy \rightarrow $(U)_{Rared} > (U)_{compressed}$

N.T.P. S.T.P.

Temperature $0^{\circ} \text{ C} = 273.15 \text{ K}$ $0.01^{\circ} \text{ C} = 273.16 \text{ K}$

Pressure $1 \text{ atm} = 1.01325 \times 10^5 \text{ N/m}^2$ 1 atm

 $= 1.01325 \times 10^{5}$ pascal

Volume 22.4 litre 22.4 litre

IDEAL GAS CONCEPT

- A gas which follows all gas laws and gas equation at every possible temperature and pressure is known as ideal or perfect gas.
- Volume of gas molecules is negligible as compared to volume of container so volume of gas = volume of container (Except 0K)
- No intermoleculer force act between gas molecules.
- Potential energy of ideal gas is zero so internal energy of ideal gas is perfectly translational K.E. of gas. It is directly proportional to absolute temperature.

So, internal energy depends only and only on its temperature.

$$E_{trans} \propto T$$

For a substance $U = U_{KE} + U_{PE}$

 $U_{\text{\tiny KE}}$: depends only on T, $U_{\text{\tiny PE}}$: depends upon intermolecular forces (Always negative)

- Specific heat of ideal gas is constant quantity and it does not change with temperature
- C_v ideal gas C_v real gas temperature temperature
- All real gases behaves as ideal gas at high temperature and low pressure.
- Volume expansion coefficient (α) and pressure expansion coefficient (β) is same for a ideal gas and

value of each is
$$\frac{1}{273}$$
 per °C $\alpha = \beta = \frac{1}{273}$ per °C

• Gas molecule have point mass and negligible volume and velocity is very high (10^7 cm/s). That's why there is no effect of gravity on them.

EQUATION OF STATE FOR IDEAL GAS

$$PV = \mu RT \quad \text{ where } \mu = \text{number of moles of gas } \Rightarrow PV = \frac{M}{M_w} RT = \left[\frac{mN}{mN_0}\right] RT = \left[\frac{R}{N_0}\right] N \ T = NkT$$

- **Ex.** By increasing temperature of gas by 5° C its pressure increases by 0.5% from its initial value at constant volume then what is initial temperature of gas?
- **Sol.** : At constant volume $T \propto P$: $\frac{\Delta T}{T} \times 100 = \frac{\Delta P}{P} \times 100 = 0.5 \Rightarrow T = \frac{5 \times 100}{0.5} = 1000 \text{K}$
- **Ex.** Calculate the value of universal gas constant at STP.
- **Sol.** Universal gas constant is given by $R = \frac{PV}{T}$

One mole of all gases at S.T.P. occupy volume V = 22.4 litre = 22.4×10^{-3} m³

$$P = 760 \text{ mm of Hg} = 760 \times 10^{-3} \times 13.6 \times 10^{3} \times 9.80 \text{ N m}^{-2}$$
 $T = 273 \text{ K}$

$$\therefore \ R = \frac{760 \times 10^{-3} \times 13.6 \times 10^{3} \times 9.80 \times 22.4 \times 10^{-3}}{273} = 8 \cdot 31 \ J \ mol^{-1} \ K^{-1}$$

- Ex. A closed container of volume 0.02 m^3 contains a mixture of neon and argon gases at a temperature of 27°C and pressure of $1 \times 10^5 \text{ Nm}^2$. The total mass of the mixture is 28 g. If the gram molecular weights of neon and argon are 20 and 40 respectively, find the masses of the individual gases in the container, assuming them to be ideal. Given: R = 8.314 J/mol/K.
- **Sol.** Let m gram be the mass of neon. Then, the mass of argon is (28 m)g.

Total number of moles of the mixture, $\mu = \frac{m}{20} + \frac{28 - m}{40} = \frac{28 + m}{40}$...(i)

Now,
$$\mu = \frac{PV}{RT} = \frac{1 \times 10^5 \times 0.02}{8.314 \times 300} = 0.8$$
 ...(ii)

By (i) and (ii), $\frac{28 + m}{40} = 0.8 \implies 28 + m = 32 \implies m = 4 \text{ gram or } mass \text{ of argon} = (28 - 4)g = 24 \text{ g}$

- Ex. Calculate the temperature of the Sun if density is 1.4 g cm⁻³, pressure is 1.4×10^9 atmosphere and average molecular weight of gases in the Sun in 2 g/mole. [Given R = 8.4 J mol⁻¹K⁻¹]
- **Sol.** $PV = \mu RT \Rightarrow T = \frac{PV}{\mu R} ...(i)$ But $\mu = \frac{M}{M_w}$ and $\rho = \frac{M}{V}$ $\therefore \mu = \frac{\rho V}{M_w}$
 - From equation (i) $T = \frac{PVM_w}{\rho VR} = \frac{PM_w}{\rho R} = \frac{1.4 \times 10^9 \times 1.01 \times 10^5 \times 2 \times 10^{-3}}{1.4 \times 1000 \times 8.4} = 2.4 \times 10^7 \text{ K}$

\\10.10.10.245\DPPDcta\rack502020-21[6080-84]\Kota\UEEAdvaraed\WooduleCoding1V-Tog1\Leoder\Physics\Themal Physics\English\03_KTG&Themady.p65



Ex. At the top of a mountain a thermometer reads 7°C and barometer reads 70 cm of Hg. At the bottom of the mountain they read 27°C and 76 cm of Hg respectively. Compare the density of the air at the top with that at the bottom.

Sol. By gas equation
$$PV = \frac{M}{M_{w}}RT \Rightarrow \frac{P}{\rho T} = \frac{R}{M_{w}} \left[\because \mu = \frac{M}{M_{w}} \text{ and } \frac{M}{V} = \rho \right]$$

Now as M_w and R are same for top and bottom $\left[\frac{P}{\rho T}\right]_T = \left[\frac{P}{\rho T}\right]_B$ So $\frac{\rho_T}{\rho_B} = \frac{P_T}{P_B} \times \frac{T_B}{T_T} = \frac{70}{76} \times \frac{300}{280} = \frac{75}{76} = 0.9868$

- Ex. During an experiment an ideal gas is found to obey an additional law VP^2 = constant. The gas is initially at temperature T and volume V. What will be the temperature of the gas when it expands to a volume 2V.
- **Sol.** By gas equation $PV = \mu RT$ and $VP^2 = constant$ on eliminating P

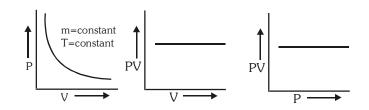
$$\left[\frac{A}{\sqrt{V}}\right]V = \mu RT \implies \sqrt{V} = \frac{\mu R}{A}T \quad \therefore \quad \frac{\sqrt{V_1}}{\sqrt{V_2}} = \left[\frac{T_1}{T_2}\right] \implies \frac{\sqrt{V}}{\sqrt{2V}} = \frac{T}{T'} \quad \Rightarrow \quad T' = \left(\sqrt{2}\right)T$$

GAS LAWS

Boyle's Law

According to it for a given mass of an ideal gas at constant temperature, the volume of a gas is inversely proportional

to its pressure, i.e., $V \propto \frac{1}{P}$ if m and T =



Constant

Ex. A sample of oxygen with volume of 500 cc at a pressure of 2 atm is compressed to a volume of 400 cc. What pressure is needed to do this if the temperature is kept constant?

Sol. Temperature is constant, so
$$P_1 V_1 = P_2 V_2 :: P_2 = P_1 \frac{V_1}{V_2} = 2 \left[\frac{500}{400} \right] = 2.5 \text{ atm}$$

- Ex. An air bubble doubles in radius on rising from bottom of a lake to its surface. If the atmosphere pressuer is equal to that due to a column of 10 m of water, then what will be the depth of the lake. (Assuming that surface tension is negligible)?
- **Sol.** Given that constant temperature, we use $P_1V_1 = P_2V_2$

 $P_2 = (10) dg$ (for water column)

 $P_1 = (10+h) dg$ (where h=depth of lake)

$$V_1 = \frac{4\pi}{3}r^3$$
, $V_2 = \frac{4\pi}{3}(2r)^3 = 8\left(\frac{4\pi}{3}r^3\right) = 8V_1$ Thus for $P_2V_2 = P_1V_1$,

We have $10 \text{ dg } (8V_1) = (10 + \text{h}) \text{ dg } V_1 \Rightarrow 80 = 10 + \text{h} \Rightarrow \text{h} = 70 \text{ m}$

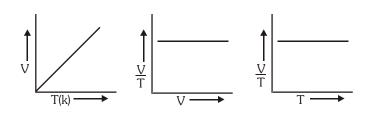
- Ex. A vessel of volume 8.0×10^{-3} m³ contains an ideal gas at 300 K and 200 k Pa. The gas is allowed to leak till the Pressure falls to 125 kPa. Calculate the amount of the gas leaked assuming that the temperature remains constant.
- **Sol.** As the gas leaks out, the volume and the temperature of the remaining gas do not change. The number of moles of the gas in the vessel in given by $n = \frac{PV}{RT}$.

The number of moles in the vessel before the leakage is $n_1 = \frac{P_1 V}{RT}$ and that after the leakage is $n_2 = \frac{P_2 V}{RT}$.

The amount leaked is
$$n_1 - n_2 = \frac{(P_1 - P_2)V}{RT} = \frac{(200 - 125) \times 10^3 \times 8.0 \times 10^{-3}}{8.3 \times 300} = 0.24 \text{ mole}$$

• Charle's Law

According to it for a given mass of an ideal gas at constant pressure, volume of a gas is directly proportional to its absolute temperature, i.e.



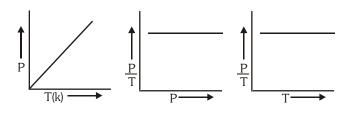
 $V \propto T$ if m and P = Constant

- Ex. 1500 ml of a gas at a room temperature of 23°C is inhaled by a person whose body temperature is 37°C, if the pressure and mass stay constant, what will be the volume of the gas in the lungs of the person?
- **Sol.** $T_1 = 273 + 37 = 310 \text{ K}$; $T_2 = 273 + 23 = 296 \text{ K}$. Pressure and amount of the gas are kept constant,

So
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
 : $V_2 = V_1 \times \frac{T_2}{T_1} = 1500 \times \frac{293}{310} = 1417.74 \text{ ml}$

Gay-Lussac's Law

According to it, for a given mass of an ideal gas at constant volume, pressure of a gas is directly proportional to its absolute temperature, i.e., $P \propto T$ if m and V = constant



Ex. A sample of O_2 is at a pressure of 1 atm when the volume is 100 ml and its temperature is 27°C. What will be the temperature of the gas if the pressure becomes 2 atm and volume remains 100 ml.

Sol.
$$T_1 = 273 + 27 = 300 \text{ K}$$

For constant volume
$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \implies T_2 = T_1 \times \frac{P_2}{P_1} = 300 \times \frac{2}{1} = 600 \text{ K} = 600 - 273 = 327^{\circ}\text{C}$$

Avogadro's Law

According to it, at same temperature and pressure of equal volumes of all gases contain equal number of molecules, i.e., $N_1 = N_2$ if P,V and T are same.

The kinetic theory of gases

• Rudolph Claussius (1822–88) and James Clark Maxwell (1831–75) developed the kinetic theory of gases in order to explain gas laws in terms of the motion of the gas molecules. The theory is based on following assumptions as regards to the motion of molecules and the nature of the gases.

Basic postulates of Kinetic theory of gases

- Every gas consists of extremely small particles known as molecules. The molecules of a given as are all identical but are different than those another gas.
- The molecules of a gas are identical, spherical, rigid and perfectly elastic point masses.
- The size is negligible in comparision to inter molecular distance $(10^{-9} \,\mathrm{m})$

Assumptions regarding motion:

- Molecules of a gas keep on moving randomly in all possible direction with all possible velocities.
- The speed of gas molecules lie between zero and infinity (very high speed).
- The number of molecules moving with most probable speeds is maximum.

Assumptions regarding collision:

• The gas molecules keep on colliding among themselves as well as with the walls of containing vessel. These collision are perfectly elastic. (ie., the total energy before collision = total energy after the collisions.)

Assumptions regarding force:

- No attractive or repulsive force acts between gas molecules.
- Gravitational attraction among the molecules is ineffective due to extremely small masses and very high speed of molecules.

Assumptions regarding pressure:

• Molecules constantly collide with the walls of container due to which their momentum changes. This change in momentum is transferred to the walls of the container. Consequently pressure is exerted by gas molecules on the walls of container.

Assumptions regarding density:

• The density of gas is constant at all points of the container.

PROPERTIES/ASSUMPTIONS OF IDEAL GAS

- The molecules of a gas are in a state of continuous random motion. They move with all possible velocities in all possible directions. They obey Newton's law of motion.
- Mean momentum = 0; Mean velocity = 0.< \vec{v} >= 0; < v^2 > \neq 0 (Non zero); < v^3 > = < v^5 > = 0
- The average distance travelled by a molecule between two successive collisions is called as mean free path (λ_m) of the molecule.
- The time during which a collision takes place is negligible as compared to time taken by the molecule to cover the mean free path so NTP ratio of time of collision to free time of motion 10^{-8} : 1.
- When a gas taken into a vessel it is uniformly distributed in entire volume of vessel such that its density, moleculer density, motion of molecules etc. all are identical for all direction, therefore root mean velocity
 - $\overline{v}_x^2 = \overline{v}_y^2 = \overline{v}_z^2 \rightarrow \text{ equal Pressure exerted by the gas in all direction } P_x = P_y = P_z = P \rightarrow \text{ equal}$
- All those assumptions can be justified, if number of gas molecules are taken very large

EXPRESSION FOR PRESSURE OF AN IDEAL GAS

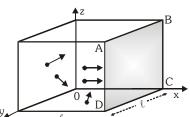
Consider an ideal gas enclosed in a cubical vessel of length ℓ . Suppose there are 'N' molecules in a gas which are moving with velocities $\vec{v}_1, \vec{v}_2, \dots, \vec{v}_N$.

If we consider any single molecule than its instantaneous velocity

 \vec{v} can be expressed as $\vec{v} = v_x \hat{i} + v_y \hat{j} + v_z \hat{k}$

Due to random motion of the molecule $v_x = v_y = v_z$

$$|v| = v_x \sqrt{3} = v_y \sqrt{3} = v_z \sqrt{3} = \sqrt{v_x^2 + v_y^2 + v_z^2}$$



Suppose a molecule of mass m is moving with a velocity v_x towards the face ABCD. It strikes the face of the cubical vessel and returns back to strike the opposite face.

Change in momentum of the molecule per collision $\Delta p = -mv_x - mv_x = -2 mv_x$

Momentum transferred to the wall of the vessel per molecule per collision $\Delta p = 2 \text{ mv}_x$

The distance travelled by the molecule in going to face ABCD and coming back is 2ℓ .

So, the time between two successive collision is $\Delta t = \frac{2\ell}{v_x}$

Number of collision per sec per molecule is $f_c = \frac{v_x}{2\ell} = \frac{\text{molecule velocity}}{\text{mean free path}}$, $f_c = \frac{v_{ms}}{\lambda_m}$ or $f_c = \frac{v_m}{\lambda_m}$

Hence momentum transferred in the wall per second by the molecule is = force on the wall

force F = (2 mv_x)
$$\frac{v_x}{2\ell} = \frac{mv_x^2}{\ell} = \frac{mv^2}{3\ell}$$

Pressure exerted by gas molecule $P = \frac{F}{A} = \frac{1}{3} \frac{mv^2}{\ell \times A}$ $\Rightarrow P = \frac{1}{3} \frac{mv^2}{V} \left[\because A \times \ell = V \right]$

Pressure exerted by gas $P = \sum \frac{1}{3} \frac{mv^2}{V} = \sum \frac{1}{3} \frac{mv^2}{V} \times \frac{N}{N} = \frac{1}{3} \frac{mN}{V} \frac{\sum v^2}{N} = \frac{1}{3} \frac{mN}{V} v_{rms}^2$

$$v_{\rm rms}^2 = \frac{3PV}{M} = \frac{3\mu RT}{\mu M_{\rm w}} \implies v_{\rm rms} = \sqrt{\frac{3RT}{M_{\rm w}}} \; , \; P = \; \frac{1}{3} \frac{M}{V} v_{\rm rms}^2 = \frac{1}{3} \rho v_{\rm rms}^2$$

- Average number of molecules for each wall = $\frac{N}{6}$. No. of molecules along each axis = $\frac{N}{3}$ ($N_x = N_y = N_z$)
- $\overline{v}_x^2 = \overline{v}_y^2 = \overline{v}_z^2 = \frac{\overline{v}_{rms}^2}{3}$ Root mean square velocity along any axis for gas molecule is $(v_{rms})_{\chi} = (v_{rms})_{y}$

$$= (v_{rms})_z = \frac{v_{rms}}{\sqrt{3}}$$

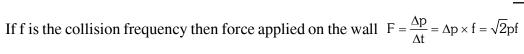
All gas laws and gas equation can be obtained by expression of pressure of gas (except Joule's law)

Ex. The mass of a hydrogen molecule is 3.32×10^{-27} kg. If 10^{23} molecules are colliding per second on a stationary wall of area 2 cm² at an angle of 45° to the normal to the wall and reflected elastically with a speed 10^3 m/s. Find the pressure exerted on the wall will be (in N/m²)

60

Sol. As the impact is elastic $|\vec{p}_1| = |\vec{p}_2| = p = mv = 3.32 \times 10^{-24} \text{ kg m/s}$

The change in momentum along the normal $\Delta p = |\vec{p}_2 - \vec{p}_1| = 2p \cos 45^\circ = \sqrt{2}p$



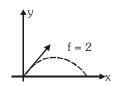
$$\therefore \qquad \text{Pressure } P = \frac{F}{A} = \frac{\sqrt{2} \, \text{pf}}{A} = \frac{\sqrt{2} \times 3.32 \times 10^{-24} \times 10^{23}}{2 \times 10^{-4}} = 2.347 \times 10^{3} \, \text{N/m}^{2}$$

DEGREE OF FREEDOM (f)

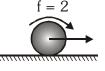
• The number of independent ways in which a molecule or an atom can exhibit motion or have energy is called it's degrees of freedom.

For example

- (a) Block has one degree of freedom, because it is confined to move in a straight line and has only one transistional degree of freedom.
- (b) The projectile has two degrees of freedom becomes it is confined to move in a plane and so it has two translational degrees of freedom.



(c) The sphere has two degrees of freedom one rotational and another translational. Similarly a particle free to move in space will have three translational degrees of freedom.



Note: In pure rolling sphere has one degree of freedom as $KE = \frac{1}{2} \text{ mv}^2 (1 + \frac{K^2}{R^2}) = \frac{7}{10} \text{ mv}^2$

- The degrees of freedom are of three types:
 - (a) **Translational Degree of freedom:** Maximum three degree of freedom are there corresponding to translational motion.
 - **(b)** Rotational Degree of freedom: The number of degrees of freedom in this case depends on the structure of the molecule.
 - (c) **Vibrational Degree of freedom :** It is exhibited at high temperatures.

Degree of freedom for different gases according to atomicity of gas at low temperature

Atomicity of gas	Translational	Rotational	Total	
Monoatomic Ex. Ar, Ne, Ideal gas etc	3	0	3	y x
Diatomic $\mathbf{Ex.~O_2,~Cl_2,~N_2}$ etc.	3	2	5	

At high temperatures a diatomic molecule has 7 degrees of freedom. (3 translational, 2 rotational and 2 vibrational)

- Ex. Calculate the total number of degrees of freedom possessed by the molecules in one cm³ of H₂ gas at NTP.
- **Sol.** 22400 cm³ of every gas constains 6.02×10^{23} molecules.
 - \therefore Number of molecules in 1 cm³ of H₂ gas = $\frac{6.02 \times 10^{23}}{22400} = 0.26875 \times 10^{20}$

Number of degrees of freedom of a H₂ gas molecule = 5

 \therefore Total number of degrees of freedom of $0.26875 \times 10^{20} \times 5 = 1.34375 \times 10^{20}$.

MAXWELL'S LAW OF EQUIPARTITION OF ENERGY

The total kinetic energy of a gas molecules is equally distributed among its all degree of freedom and the energy associated with each degree of freedom at absolute temperature T is $\frac{1}{2}kT$

For one molecule of gas

Energy related with each degree of freedom = $\frac{1}{2}$ kT

 $Energy \ related \ with \ all \ degree \ of \ freedom = \frac{f}{2}kT \ \because \overline{v}_x^2 = \overline{v}_y^2 = \overline{v}_z^2 = \frac{\overline{v}_{rms}^2}{3} \Longrightarrow \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$

So energy related with one degree of freedom = $\frac{1}{2}$ m $\frac{v_{rms}^2}{3} = \frac{3}{2} \frac{kT}{3} = \frac{1}{2}kT$

- Ex. A cubical box of side 1 meter contains helium gas (atomic weight 4) at a pressure of 100 N/m². During an observation time of 1 second, an atom travelling with the root–mean–square speed parallel to one of the edges of the cube, was found to make 500 hits with a particular wall, without any collision with other atoms. Take $R = \frac{25}{3} \text{ J/mol-K}$ and $k = 1.38 \times 10^{-23} \text{ J/K}$.
 - (a) Evaluate the temperature of the gas.
 - (b) Evaluate the average kinetic energy per atom.
 - (c) Evaluate the total mass of helium gas in the box.
- **Sol.** Volume of the box = $1m^3$, Pressure of the gas = 100 N/m^2 . Let T be the temperature of the gas
 - (a) Time between two consecutive collisions with one wall = $\frac{1}{500}$ sec

This time should be equal to $\frac{2I}{v_{\text{\tiny ms}}},$ where $_{\ell}$ is the side of the cube.



$$2\ell v_{\rm rms} = \frac{1}{500} \implies v_{\rm rms} = 1000 \text{ m/s} \ \therefore \ \sqrt{\frac{3RT}{M}} \ = 1000 \implies T = \frac{(1000)^2 \, \text{M}}{3R} = \frac{(10)^6 \, (3 \times 10^{-3})}{3 \left(\frac{25}{3}\right)} = 160 \, \text{K}$$

- (b) Average kinetic energy per atom = $\frac{3}{2}$ kT = $\frac{3}{2}$ [(1.38 × 10⁻²³) = 160] J = 3.312 ×⁻²¹ J
- (c) From PV = nRT = $\frac{m}{M}$ RT, Mass of helium gas in the box m= $\frac{PVM}{RT}$

Substituting the values,
$$m = \frac{(100)(1)(4 \times 10^{-3})}{\left(\frac{25}{3}\right)(160)} = 3.0 \times 10^{-4} \text{ kg}$$

Ε

DIFFERENT K.E. OF GAS (INTERNAL ENERGY)

• Translatory kinetic energy ($\mathbf{E}_{\mathbf{T}}$) $\mathbf{E}_{\mathbf{T}} = \frac{1}{2} \mathbf{M} \mathbf{v}_{rms}^2 = \frac{3}{2} \mathbf{P} \mathbf{V}$

Kinetic energy of volume V is = $\frac{1}{2}$ Mv_{rms}² Note: Total internal energy of ideal gas is kinetic

• Energy per unit volume or energy density (E_v)

• Molar K.E. or Mean Molar K.E. (E)

$$E = \frac{1}{2} M_w v_{ms}^2 \text{ for } N_0 \text{ molecules or } M_w \text{ (gram)} \qquad E = \frac{3}{2} RT = \frac{3}{2} N_0 kT$$

• Molecular kinetic energy or mean molecular K.E. (\bar{E})

$$E = \frac{1}{2} \, M_{\rm w} v_{\rm rms}^2 \, , \, \overline{E} = \frac{E}{N_0} = \frac{3}{2} \, \frac{RT}{N_0} \Longrightarrow \overline{E} = \frac{3}{2} \, kT$$

GOLDEN KEY POINT

- Except 0 K, at any temperature T , $E > E_m > \overline{E}$
- At a common temperature, for all ideal gas

E and \overline{E} are same while $E_{_m}$ is different and depends upon nature of gas ($M_{_w}$ or m)

• For thermal equilibrium of gases, temperature of each gas is same and this temperature called as temperature of mixture (T_m) which can be find out on basis of conservation of energy (All gases are

of same atomicity).
$$T_{m} = \frac{\sum NT}{\sum N} = \frac{N_{1}T_{1} + N_{2}T_{2} + \dots + N_{n}T_{n}}{N_{1} + N_{2} \dots + N_{n}}$$

• **1 mole gas :** Mean kinetic energy = $\frac{3}{2}$ RT ; Total kinetic energy = $\frac{f}{2}$ RT

1 molecule of gases : Mean kinetic energy = $\frac{3}{2}$ kT; Total kinetic energy = $\frac{f}{2}$ kT

 $f \rightarrow \text{Degree of freedom}$

- **Ex.** Two ideal gases at temperature T₁ and T₂ are mixed. There is no loss of energy. If the masses of molecules of the two gases are m₁ and m₂ and number of their molecules are n₁ and n₂ respectively. Find the temperature of the mixture.
- **Sol.** Total energy of molecules of first gas = $\frac{3}{2}$ n₁kT₁, Total energy of molecules of second gas = $\frac{3}{2}$ n₂kT₂ Let temperature of mixture be T then total energy of molecules of mixture = $\frac{3}{2}$ k(n₁ + n₂)T

$$\therefore \frac{3}{2}(n_1 + n_2)kT = \frac{3}{2}k(n_1T_1 + n_2T_2) \Longrightarrow T = \frac{n_1T_1 + n_2T_2}{(n_1 + n_2)}$$

- **Ex.** The first excited state of hydrogen atom is 10.2 eV above its ground state. What temperature is needed to excite hydrogen atoms to first excited level.
- **Sol.** K.E. of the hydrogen atom $\frac{3}{2}kT = 10.2 \text{ eV} = 10.2 \times (1.6 \times 10^{-19}) \text{ J}$

$$\Rightarrow \ T = \frac{2}{3} \times \frac{10.2 \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23}} = 7.88 \times 10^4 \ K$$

DIFFERENT SPEEDS OF GAS MOLECULES

• Average velocity

Because molecules are in random motion in all possible direction in all possible velocity. Therefore, $\vec{v}_1 + \vec{v}_2 + \vec{v}_3 + \vec{v}_4 + \vec{v}_5 + \vec{v}_6 + \vec{v}_7 + \vec{v}_8 + \vec{v}_8$

the average velocity of the gas in molecules in container is zero. $<\vec{v}>=\frac{\vec{v}_1+\vec{v}_2+....\vec{v}_N}{N}=0$

rms speed of molecules
$$v_{rms} = \sqrt{\frac{3P}{\rho}} = \sqrt{\frac{3RT}{M_w}} = \sqrt{\frac{3kT}{m}} = 1.73\sqrt{\frac{kT}{m}}$$

Mean speed of molecules: By maxwell's velocity distribution law v_{M} or $\langle |\vec{v}| \rangle = v_{M}$

$$<|\vec{v}|>=v_{mean}=\frac{|\vec{v}_1|+|\vec{v}_2|+.....|\vec{v}_n|}{N}=\sqrt{\frac{8P}{\pi}}=\sqrt{\frac{8RT}{\pi M_w}}=\sqrt{\frac{8kT}{\pi m}}=1.59\sqrt{\frac{kT}{m}}$$

Most probable speed of molecules (v_{mn})

At a given temperature, the speed to which maximum number of molecules belongs is called as most

$$probable \ speed \ (v_{mp}) \qquad v_{mp} = \sqrt{\frac{2P}{\rho}} \ = \ \sqrt{\frac{2RT}{M_w}} \ = \ \sqrt{\frac{2kT}{m}} = 1.41 \quad \sqrt{\frac{kT}{m}}$$

Ex. The velocities of ten particles in ms^{-1} are 0, 2, 3, 4, 4, 4, 5, 5, 6, 9. Calculate

(i) average speed and (ii) rms speed (iii) most probable speed.

Sol. (i) average speed,
$$v_{av} = \frac{0 + 2 + 3 + 4 + 4 + 4 + 5 + 5 + 6 + 9}{10} = \frac{42}{10} = 4.2 \text{ ms}^{-1}$$

(ii) rms speed,
$$v_{rms} = \left[\frac{(0)^2 + (2)^2 + (3)^2 + (4)^2 + (4)^2 + (4)^2 + (5)^2 + (5)^2 + (6)^2 + (9)^2}{10}\right]^{1/2} = \left[\frac{228}{10}\right]^{1/2} = 4.77 \text{ ms}^{-1}$$

(iii) most probable speed $v_{mp} = 4 \text{ m/s}$

Ex. At what temperature, will the root mean square velocity of hydrogen be double of its value at S.T.P., pressure remaining constant?

Sol. Let v_1 be the r.m.s. velocity at S.T.P. and v_2 be the r.m.s. velocity at unknown temperature T_2 .

$$\therefore \frac{v_1^2}{v_2^2} = \frac{T_1}{T_2} \quad \text{or} \quad T_2 = T_1 \left[\frac{v_2}{v_1} \right]^2 = 273 \times (2)^2 = 273 \times 4 = 1092 \text{ K} = (1092 - 273) = 819^{\circ}\text{C}$$

Ex. Calculate rms velocity of oxygen molecule at 27°C

Sol. Temperature, $T = 27^{\circ} C$ \Rightarrow 273 + 27 = 300 K, Molecular weight of oxygen = 32×10^{-3} kg and R = 8.31 J mol⁻¹ K⁻¹

rms velocity is
$$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3 \times 8 \cdot 31 \times 300}{32 \times 10^{-3}}} = 483.5 \text{ ms}^{-1}$$

Ex. Calculate the kinetic energy of a gram moelcule of argon at 127°C.

Sol. Temperature, $T = 127^{\circ}C = 273 + 127 = 400 \text{ K}$, R = 8.31 J/mol K

K.E. per gram molecule of argon = $\frac{3}{2}$ R T = $\frac{3}{2}$ × 8.31 × 400 = 4986 J

1/10.10.100.245/DTPDde/node/06/2020-21(B0B0-BA)/Kota/UE[Advanced/Wodule/Coding[V-Tog]/Lecder/Physics/Themd Physics/Themd Physics

THERMODYNAMICS

Branch of physics which deals with the inter–conversion between heat energy and any other form of energy is known as thermodynamics. In this branch of physics we deals with the processes involving heat, work and internal energy. In this branch of science the conversion of heat into mechanical work and vice versa is studied.

• Thermodynamical System

The system which can be represented in of pressure (P), volume (V) and temperature (T), is known thermodynamic system. A specified portion of matter consisting of one or more substances on which the effects of variables such as temperature, volume and pressure are to be studied, is called a system. e.g. A gas enclosed in a cylinder fitted with a piston is a system.

Surroundings

Anything outside the system, which exchanges energy with the system and which tends to change the properties of the system is called its surroundings.

• Heterogeneous System

A system which is not uniform throughout is said to be heterogeneous. e.g. A system consisting of two or more immiscible liquids.

• Homogeneous System

A system is said to be homogeneous if it is completely uniform throughout. e.g. Pure solid or liquid.

Isolated System

A system in which there can be no exchange of matter and energy with the surroundings is said to be an isolated system.

Universe

The system and its surroundings are together known as the universe.

Thermodynamic variables of the system

(i) Composition (μ)

(ii) Temperature (T) (iii) Volume (V)

(iv) Pressure (P)

• Thermodynamic state

The state of a system can be described completely by composition, temperature, volume and pressure. If a system is homogeneous and has definite mass and composition, then the state of the system can be described by the remaining three variables namely temperature, pressure and volume. These variables are interrelated by equation $PV = \mu RT$ The thermodynamic state of the system is its condition as identified by two independent thermodynamic variables (P, V or P, T or V, T).

• Zeroth law of thermodynamics

If objects A and B are separately in thermal equilibrium with a third object C (say thermometer), then objects A and B are in thermal equilibrium with each other. Zeroth law of thermodynamics introduce the concept of temperature. Two objects (or systems) are said to be in thermal equilibrium if their temperatures are the same.

In measuring the temperature of a body, it is important that the thermometer be in the thermal equilibrium with the body whose temperature is to be measured.

• Thermal equilibrium

Thermal equilibrium is a situation in which two objects in thermal contact cease to exchange energy by the process of heat. Heat is the transfer of energy from one object to another object as a result of a difference in temperature between them.

• Internal Energy

Internal energy of a system is the energy possessed by the system due to molecular motion and molecular configuration. The energy due to molecular motion is called internal kinetic energy (U_k) and that due to molecular configuration is called internal potential energy (U_p) . $dU = dU_k + dU_p$

If there no intermolecular forces, then $dU_p = 0$ and $dU = dU_k = m c_v dT$

 $c_y =$ Specific heat at constant volume and dT =Infinitesimal change in temperature

m = Mass of system

M = Molecular weight

Molar heat capacity $C_v = Mc_v$

For
$$\mu$$
-moles of ideal gas $dU = \mu C_{\nu} dT = \frac{m}{M} C_{\nu} dT$

Internal energy in the absence of inter-molecular forces is simply the function of temperature and state only, it is independent of path followed. $\Delta U = U_f - U_i$

 U_i = Internal energies in initial state and U_f = Internal energies in final state

• Thermodynamic Processes

In the thermodynamic process pressure, volume, temperature and entropy of the system change with time.

Thermodynamic process is said to take place if change occurs in the state of a thermodynamic system.

• Sign convention used for the study of thermodynamic processes

Heat gained by a system	Positive	
Heat lost by a system	Negative	
The work done by a system	Positive	
Work done on the system	Negative	
Increase in the internal energy of system	Positive	
Decrease in the internal energy of system	Negative	

• Indicator Diagram or P-V Diagram

In the equation of state of a gas $PV = \mu RT$

Two thermodynamic variables are sufficient to describe the behavior of a thermodynamic system.

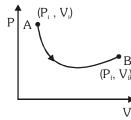
If any two of the three variables P, V and T are known then the third can be calculated.

P-V diagram is a graph between the volume V and the pressure P of the system.

The volume is plotted against X-axis while the pressure is plotted against Y-axis.

The point A represents the initial stage of the system. Initial pressure of the system is P_i and initial volume of the system V_i .

The point B represents the final state of the system. P_f and V_f are the final pressure and final volume respectively of the system. The points between A and B represent the intermediate states of the system. With the help of the indicator diagram we calculate the amount of work done by the gas or on the gas during expansion or compression.



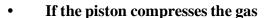
ALLEN

WORK DONE BY THERMODYNAMIC SYSTEM

One of the simple example of a thermodynamic system is a gas in a cylinder with a movable piston.

• If the gas expands against the piston

Gas exerts a force on the piston and displace it through a distance and does work on the piston.



When piston moved inward, work is done on the gas.

• The work associated with volume changes

If pressure of gas on the piston = P.

Then the force on the piston due to gas is F = PA

When the piston is pushed outward an infinitesimal distance dx,

the work done by the gas is $dW = F \times dx = PA dx$

The change in volume of the gas is dV = Adx, $\therefore dW = PdV$

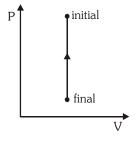
For a finite change in volume from V_i to V_f , this equation is then integrated between V_i to V_f to find the

net work done
$$W = \int_{V_i}^{V_i} dW = \int_{V_i}^{V_i} PdV$$

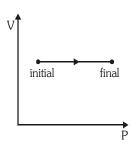
Hence the work done by a gas is equal to the area under P–V graph.

Following different cases are possible.

(i) Volume is constant



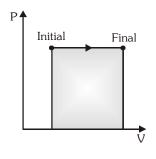
or



$$V = constant$$
 and $W_{AB} = 0$

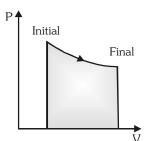
or

(ii) Volume is increasing



V is increasing

 $W_{AB} > 0$

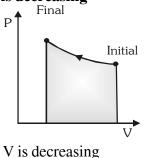


 $W_{AB} = Shaded area$

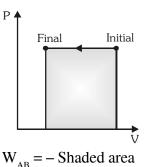
initial



(iii) Volume is decreasing



or



FIRST LAW OF THERMODYNAMICS

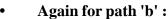
Let a gas in a cylinder with a moveable piston changes from an initial

equilibrium state to a final equilibrium state.

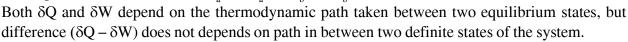
System change its state through path 'a':

The heat absorbed by the system in this process = δQ_{a}

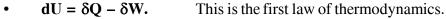
The work done by the system = δW_{a}



Heat absorbed by the system = δQ_b , Work done by the system = δW_b . It is experimental fact that the $\delta Q_a - \delta W_b = \delta Q_b - \delta W_b$



So, there is a function (internal energy) of the thermodynamic coordinates (P, V and T) whose final value (U_f) minus its initial value (U_i) equals the change $\delta Q - \delta W$ in the process.



Heat supplied to the system and work done by the system are path dependent so they are denoted by δQ and δW respectively. Change in internal energy $\Delta U = U_f - U_i$ does not depends on path it depends only on initial and final positions of the system. So, it is denoted by dU (or ΔU)

• First Law of Thermodynamics

If some quantity of heat is supplied to a system capable of doing external work, then the quantity of heat absorbed by the system is equal to the sum of the increase in the internal energy of the system and the external work done by the system. $\delta Q = dU + \delta W$ or $Q = W + \Delta U$

- * This law is applicable to every process in nature
- * The first law of thermodynamics introduces the concept of internal energy.
- * The first law of thermodynamics is based on the law of conservation of energy.
- * δQ , dU and δW must be expressed in the same units (either in units of work or in units of heat).
- * This law is applicable to all the three phases of matter, i.e., solid, liquid and gas.
- * dU is a characteristic of the state of a system, it may be any type of internal energy–translational kinetic energy, rotational kinetic energy, binding energy etc.

Limitations of first law of thermodynamics :

It does not explain the direction of heat flow and it does not explain how much amount of heat given will be converted into work.

• Significance of the first law of thermodynamics :

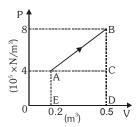
The first law of thermodynamics tells us that it is impossible to get work from any machine without giving it an equivalent amount of energy.

- The pressure in monoatomic gas increases linearly from 4×10^5 Nm⁻² to $8 \times 10^{+5}$ Nm⁻² when its Ex. volume increases from 0.2m³ to 0.5 m³. Calculate.
 - (i) Work done by the gas,
- (ii) Increase in the internal energy,
- (iii) Amount of heat supplied,
- (iv) Molar heat capacity of the gas $R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$

$$P_2 = 8 \times 10^{+5} \text{ Nm}^{-2}, V_1 = 0.2 \text{ m}^3, V_2 = 0.5 \text{ m}^3$$

Sol. $P_1 = 4 \times 10^5 \text{ Nm}^{-2}$ $P_2 = 8 \times 10^{+5} \text{ Nm}^{-2}$, $V_1 = 0.2 \text{ m}^3$, $V_2 = 0.5 \text{ m}^3$ (i) Work done by the gas = Area under P–V graph (Area ABCDEA)

$$= \frac{1}{2} (AE + BD) \times AC = \frac{1}{2} (4 \times 10^5 + 8 \times 10^5) \times (0.5 - 0.2)$$
$$= \frac{1}{2} \times 12 \times 10^5 \times 0.3 = 1.8 \times 10^5 J$$



Increase in internal energy $\Delta U = C_V (T_2 - T_1) = \frac{C_V}{R} R (T_2 - T_1) = \frac{C_V}{R} (P_2 V_2 - P_1 V_1)$ (ii)

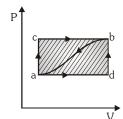
For monoatomic gas

$$C_{V} = \frac{3}{2}R$$
 $\therefore \Delta U = \frac{3}{2} [(8 \times 10^{5} \times 0.5) - (4 \times 10^{5} \times 0.2)] = \frac{3}{2} [4 \times 10^{5} - 0.8 \times 10^{5}] = 4.8 \times 10^{5} J$

(iii) $Q = \Delta U + W = 4.8 \times 10^5 + 1.8 \times 10^5 = 6.6 \times 10^5 J$

$$(iv) \quad C = \frac{Q}{\eta \Delta T} = \frac{QR}{\eta R \Delta T} = \frac{QR}{\eta (P_2 V_2 - P_1 V_1)} = \frac{6.6 \times 10^5 \times 8.31}{1 \times 3.2 \times 10^5} = 17.14 \text{ J/mole K}$$

When a system is taken from state a to state b, in figure along the path $a \rightarrow c \rightarrow b$, 60 J of heat flow into the system, and 30 J of work is



- (i) How much heat flows into the system along the path a \rightarrow $d \rightarrow b$ if the work is 10 J.
- (ii) When the system is returned from b to a along the curved path, the work done by the system is -20 J. Does the system absorb or liberate heat, and how much?
- (iii) If, $U_a = 0$ and $U_d = 22$ J, find the heat absorbed in the process $a \rightarrow d$ and $d \rightarrow b$.
- **Sol.** For the path a, c, b, $\Delta U = Q W = 60 30 = 30 \text{ J or } U_b U_a = 30 \text{ J}$
 - $Q = \Delta U + W = 30 + 10 = 40 J$ (i) Along the path a, d, b,
 - (ii) Along the curved path b, a, $Q = (U_a U_b) + W = (-30) + (-20) = -50$ J, heat flows out the system (iii) $Q_{ad} = 32 J; Q_{db} = 8 J$

ISOMETRIC OR ISOCHORIC PROCESS

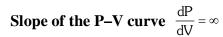
Isochoric process is a thermodynamic process that takes place at constant volume of the system, but pressure and temperature varies for change in state of the system.

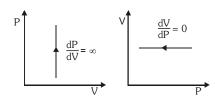
Equation of state $P = constant \times T$ (P and T are variable, V is constant)

Work done In this process volume remains constant $\Delta V = 0$ or $dV = 0 \Rightarrow W = \int_{V}^{V_f} P dV = 0$

Form of first Law $Q = \Delta U$

It means whole of the heat supplied is utilized for change in internal energy of the system. $Q = \Delta U = \mu C_v \Delta T$





Specific heat at constant volume (C_v)

The quantity of heat required to raise the temperature of 1 gram mole gas through 1 °C at constant volume is equal to the specific heat at constant volume.

- A gas enclosed in a cylinder having rigid walls and a fixed piston. When heat is added to the gas, there would be no change in the volume of the gas.
- When a substance melts, the change in volume is negligibly small. So, this may be regarded as a nearly isochoric process.
- Heating process in pressure cooker is an example of isometric process.
- Ex. An ideal gas has a specific heat at constant pressure $C_p = \frac{5R}{2}$. The gas is kept in a closed vessel of volume 0.0083 m³ at a temperature of 300K and a pressure of 1.6 × 10⁶ Nm⁻². An amount of 2.49×10^4 J of heat energy is supplied to the gas. Calculate the final temperature and pressure of the gas.

Sol.
$$C_V = C_P - R = \frac{5R}{2} - R = \frac{3R}{2}$$
, $\Delta V = 0$, $T_1 = 300$ K, $V = 0.0083$ m³, $P_1 = 1.6 \times 10^6$ Nm⁻²

From first law of thermodynamics $Q = \Delta U + P\Delta V \implies \Delta U = Q = 2.49 \times 10^4 \text{ J}$

From gas equation n =
$$\frac{PV}{RT} = \frac{1.6 \times 10^6 \times 0.0083}{8.3 \times 300} = \frac{16}{3}$$

$$\therefore \Delta U = nC_v \Delta T \Rightarrow \Delta T = \frac{\Delta U}{nC_v} = \frac{2.49 \times 10^4 \times 6}{3 \times 8.3 \times 16} = 375 \text{ K}$$

Final temperature = 300 + 375 = 675K

According to pressure law
$$P \propto T \Rightarrow \frac{P_2}{P_1} = \frac{T_2}{T_1} \Rightarrow P_2 = \frac{T_2}{T_1} \times P_1 = \frac{1.6 \times 10^6 \times 675}{300} = 3.6 \times 10^6 \text{ Nm}^{-2}$$

Ex. 5 moles of oxygen is heated at constant volume from 10°C to 20°C. What will be change in the internal energy of the gas? The gram molecular specific heat of oxygen at constant pressure.

 $C_p = 8$ cal/mole and R = 8.36 joule/mole °C.

Sol.
$$C_v = C_p - R = 8 - 2 = 6$$
 cal/mole °C

:. Heat absorbed by 5 moles of oxygen at constant volume

$$Q = nC_v \Delta T = 5 \times 6 (20 - 10) = 30 \times 10 = 300 \text{ cal}$$

At constant volume $\Delta V = 0$. $\therefore \Delta W = 0$

:. From first law of thermodynamics $Q = \Delta U + W \Rightarrow 300 = \Delta U + 0 \Rightarrow \Delta U = 300$ cal

ISOBARIC PROCESS

Isobaric process is a thermodynamic process that takes place at constant pressure, but volume and temperature varies for change in state of the system.

• Equation of state
$$V = constant \times T \text{ or } V \propto T$$

• Work done In this process pressure remains constant $\Delta P = 0$

Work done
$$W = \int_{V_f}^{V_f} P dV = P(V_f - V_i)$$

• Form of first Law
$$Q = \Delta U + P \ (V_f - V_i)$$

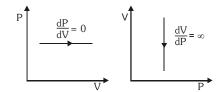
$$\mu \ C_p \ dT = \mu \ C_v \ dT + P (V_f - V_i)$$

\\10.10.10.245\DTPDato\node06\2020-21[8080-Ba]\Kota\UEFAdvanced]\WoddJeCoding[V-Tag]\Leader\Physics\Themud Physics\English\03_KTG&Themody.p65

Ε

It is clear that heat supplied to the system is utilized for:

- (i) Increasing internal energy and
- (ii) Work done against the surrounding atmosphere.
- Slope of the PV curve: $\left(\frac{dP}{dV}\right)_{\text{isobaric}} = 0$



• Specific heat at constant pressure (C_p)

The quantity of heat required to raise the temperature of 1 gram mole gas through 1°C at constant pressure is equal to the specific heat. Heating of water at atmospheric pressure. • Melting of solids and boiling of liquids at atmospheric pressure.

- Ex. At normal pressure and 0°C temperature the volume of 1 kg of ice is reduced by 91 cm³ on melting. Latent heat of melting of ice is 3.4×10^5 J/kg. Calculate the change in the internal energy when 2kg of ice melts at normal pressure and 0°C. (P=1.01 × 10⁵ Nm⁻²)
- **Sol.** Heat energy absorbed by 2 kg of ice for melting $Q = mL = 2 \times 3.4 \times 10^5 = 6.8 \times 10^5 J$ Change in volume of 2 kg of ice = $2 \times 91 = 182$ cm³ = 182×10^{-6} m³

$$\therefore$$
 W = P Δ V = 1.01 × 10⁵ × (-182 × 10⁻⁶) = -18.4 J

Since, work is done on ice so work W is taken -ve. Now from first law of thermodynamics

$$Q = \Delta U + W \implies \Delta U = Q - W = 6.8 \times 10^5 - (-18.4) = (6.8 \times 10^5 + 18.4)J$$

Ex. What amount of heat must be supplied to 2.0×10^{-2} kg of nitrogen (at room temperature) to raise the temperature by 45°C at constant pressure. Molecular mass of $N_2 = 28$, R = 8.3 J mol⁻¹ K⁻¹.

Sol. Here
$$m = 2 \times 10^{-2} \text{ kg}$$
, $\Rightarrow n = \frac{m}{M} = \frac{2 \times 10^{-2}}{28 \times 10^{-3}} = \frac{5}{7} \& C_p = \frac{7}{2} R$

:
$$Q = nC_p \Delta T = \frac{5}{7} \times \frac{7}{2} \times 8.3 \times 45 = 933.75 \text{ J}$$

ISOTHERMAL PROCESS

In this process pressure and volume of system change but temperature remains constant.

In an isothermal process, the exchange of heat between the system and the surroundings is allowed. Isothermal process is carried out by either supplying heat to the substance or by extracting heat from it. A process has to be extremely slow to be isothermal.

• Equation of state

$$PV = constant (\mu RT) (T is constant)$$

Work Done

Consider μ moles of an ideal gas, enclosed in a cylinder, at absolute temperature T, fitted with a frictionless piston. Suppose that gas undergoes an isothermal expansion from the initial state (P_1, V_1) to the final state (P_2, V_2) .

$$\therefore \ \, \text{Work done}: \ \, W = \int_{V_1}^{V_2} \frac{\mu RT}{V} dV \ \, = \ \, \mu RT \! \int_{V_1}^{V_2} \frac{dV}{V} = \ \, \mu RT \big[log_e \, V \big]_{V_1}^{V_2}$$

$$= \mu RT \left[\log_e V_2 - \log_e V_1\right] = \mu RT \log_e \left[\frac{V_2}{V_1}\right]$$

$$\Rightarrow W = 2.303 \mu RT \log_{10} \left[\frac{P_1}{P_2} \right] [\because P_1 V_1 = P_2 V_2]$$

Form of First Law

There is no change in temperature and internal energy of the system depends on temperature only

So
$$\Delta U = 0$$
, $Q = 2.303 \mu RT log_{10} \left[\frac{V_2}{V_1} \right]$

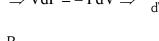
It is clear that Whole of the heat energy supplied to the system is utilized by the system in doing external work. There is no change in the internal energy of the system.

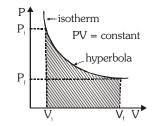
Slope of the isothermal curve

For an isothermal process, PV = constant

Differentiating,
$$PdV + VdP = 0$$

Differentiating,
$$PdV + VdP = 0$$
 $\Rightarrow VdP = -PdV \Rightarrow \frac{dP}{dV} = -\frac{P}{V}$

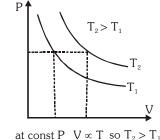




Slope of isothermal curve, $\left[\frac{dP}{dV}\right]_{isothermal} = -\frac{P}{V}$

For a given system:

- The product of the pressure and volume of a given mass of a perfect gas remains constant in an isothermal process.
- Boyle's law is obeyed in an isothermal process.
- A graph between pressure and volume of a given mass of a gas at constant temperature is known as isotherm or isothermal of the gas.
- Two isotherms for a given gas at two different temperatures T_1 and T_2 are shown in figure.



- The curves drawn for the same gas at different temperatures are mutually parallel and do not cut each other.
- If two isotherms intersect each other at a single point we get same value of P and V at intersection point.
- $PV = \mu RT_1$ for temperature T_1 and $PV = \mu RT_2$ for temperature T_2 .

It means $T_1 = T_2$, which is not possible.

- An ideal gas enclosed in a conducting cylinder fitted with a conducting piston. Let the gas be allowed to expand very-very slowly.
- This shall cause a very slow cooling of the gas, but heat will be conducted into the cylinder from the surrounding. Hence the temperature of the gas remains constant. If the gas is compressed very-very slowly, heat will be produced, but this heat will be conducted to the surroundings and the temperature of the gas shall remain constant.
- The temperature of a substance remains constant during melting. So, the melting process is an isothermal process.
- Boiling is an isothermal process, when a liquid boils, its temperature remains constant.
- If sudden changes are executed in a vessel of infinite conductivity then they will be isothermal.



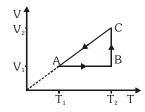
Ex. Two moles of a gas at 127°C expand isothermally until its volume is doubled. Calculate the amount of work done.

Sol.
$$n = 2$$
, $T = 127 + 273 = 400K$, $\frac{V_2}{V_1} = 2$

From formula
$$W = 2.3026 \text{ nRT } \log_{10} \frac{V_2}{V_1} = 2.3026 \times 2 \times 8.3 \times 400 \times \log_{10} 2$$

$$= 2.3026 \times 2 \times 8.3 \times 400 \times 0.3010 \approx 4.6 \times 10^{3} \text{J}$$

Ex. Figure shows a process ABCA performed on an ideal gas.



Find the net heat given to the system during the process.

Sol. Since the process is cyclic, hence the change in internal energy is zero.

The heat given to the system is then equal to the work done by it.

The work done in part AB is $W_1 = 0$ (the volume remains constant). The part BC represents an

isothermal process so that the work done by the gas during this part is $W_2 = nRT_2 \ell n \frac{V_2}{V_1}$

During the part CA $V \propto T$ So, V/T is constant and hence, $P = \frac{nRT}{V}$ is constant

The work done by the gas during the part CA is $W_3 = P(V_1 - V_2) = nRT_1 - nRT_2 = -nR(T_2 - T_1)$.

The net work done by the gas in the process ABCA is $W = W_1 + W_2 + W_3 = nR \left[T_2 \ell n \frac{V_2}{V_1} - (T_2 - T_1) \right]$

The same amount of heat is given to the gas.

ADIABATIC PROCESS

It is that thermodynamic process in which pressure, volume and temperature of the system change but there is no exchange of heat between the system and the surroundings.

A sudden and quick process will be adiabatic since there is no sufficient time available for exchange of heat so process adiabatic.

Equation of state: $PV = \mu RT$

Equation for adiabatic process PV^{γ} = constant

Work done

Let initial state of system is (P_1, V_1, T_1) and after adiabatic change final state of system is (P_2, V_2, T_2) then we can write $P_1 V_1^{\gamma} = P_2 V_2^{\gamma} = K$ (here K is const.)

$$So \hspace{1cm} W = \int_{V_1}^{V_2} P dV = K \int_{V_1}^{V_2} V^{-\gamma} dV = K \bigg(\frac{V^{-\gamma+1}}{-\gamma+1} \bigg)_{V_1}^{V_2} = \frac{K}{(-\gamma+1)} \quad \bigg[V_2^{-\gamma+1} - V_1^{-\gamma+1} \bigg] \quad \bigg(\because \quad K = P_1 V_1^{\gamma} = P_2 V_2^{\gamma} \bigg)$$

$$\Rightarrow W = \frac{1}{(\gamma - 1)} \left[P_1 V_1^{\gamma} V_1^{-\gamma} . V_1 - P_2 V_2^{\gamma} V_2^{-\gamma} . V_2 \right] = \frac{1}{(\gamma - 1)} \left[P_1 V_1 - P_2 V_2 \right]$$

$$\Rightarrow W = \frac{\mu R}{(\gamma - 1)} \left(T_1 - T_2 \right) \quad (\because PV = \mu RT)$$

Form of first law : $dU = -\delta W$

It means the work done by an ideal gas during adiabatic expansion (or compression) is on the cost of change in internal energy proportional to the fall (or rise) in the temperature of the gas.

If the gas expands adiabatically, work is done by the gas. So, W_{adia} is positive.

The gas cools during adiabatic expansion and $T_1 > T_2$.

If the gas is compressed adiabatically, work is done on the gas. So, W_{adia} is negative.

The gas heats up during adiabatic compression and $T_1 < T_2$

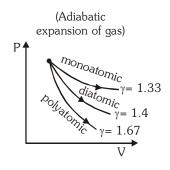
Slope of the adiabatic curve

For an adiabatic process, $PV^{\gamma} = constant$

Differentiating, $P^{\gamma} V^{\gamma-1} dV + V^{\gamma} dP = 0$

$$\Rightarrow V^{\gamma} \; dP = - \; \gamma \; P V^{\gamma - 1} \; dV \\ \Rightarrow \frac{dP}{dV} = - \frac{\gamma P V^{\gamma - 1}}{V^{\gamma}} = - \gamma \frac{P}{V} = \gamma \left(- \frac{P}{V} \right)$$

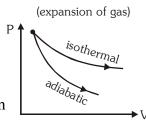
Slope of adiabatic curve, $\left[\frac{dP}{dV}\right]_{adiabatic} = -\frac{\gamma P}{V}$



Slope of adiabatic is greater than the slope of isotherm

$$\left[\frac{dP}{dV}\right]_{adia} = \gamma \left[-\frac{P}{V}\right] = \gamma \left[\frac{dP}{dV}\right]_{iso} \Rightarrow \frac{\text{slope of adiabatic changes}}{\text{slope of isothermal changes}} = \gamma$$

Since $\boldsymbol{\gamma}$ is always greater than one so an adiabatic is steeper than an isotherm



Examples of adiabatic process

- A gas enclosed in a thermally insulated cylinder fitted with a non–conducting piston. If the gas is compressed suddenly by moving the piston downwards, some heat is produced. This heat cannot escape the cylinder. Consequently, there will be an increase in the temperature of the gas.
- If a gas is suddenly expanded by moving the piston outwards, there will be a decrease in the temperature of the gas.
- Bursting of a cycle tube.
- Propagation of sound waves in a gas.
- In diesel engines burning of diesel without spark plug is done due to adiabatic compression of diesel vapour and air mixture

- Why it is cooler at the top of a mountain than at sea level? Ex.
- Sol. Pressure decreases with height. Therefore if hot air rises, it suffers adiabatic expansion.

 $\Delta Q = \Delta U + \Delta W \Rightarrow \Delta U = -\Delta W [\cdot \cdot \Delta Q = 0]$ From first law of thermodynamics

This causes a decrease in internal energy and hence a fall of temperature.

 $2m^3$ volume of a gas at a pressure of 4×10^5 Nm⁻² is compressed adiabatically so that its volume becomes 0.5m³. Find the new pressure. Compare this with the pressure that would result if the compression was isothermal. Calculate work done in each process. $\gamma = 1.4$

Sol.
$$V_1 = 2m^3$$
, $P_1 = 4 \times 10^5 \text{ Nm}^{-2}$, $V_2 = 0.5m^3$

In adiabatic process
$$P_1V_1^{\gamma} = P_2V_2^{\gamma} \Rightarrow P_2 = 4 \times 10^5 \left[\frac{2}{0.5}\right]^{1.4} = 4 \times 10^5 \text{ (4)}^{1.4} = 2.8 \times 10^6 \text{ Nm}^{-2}$$

In isothermal process
$$P_1V_1 = P_2V_2 \Rightarrow P_2 = \frac{P_1V_1}{V_2} = \frac{4 \times 10^5 \times 2}{0.5} = 1.6 \times 10^6 \, \text{Nm}^{-2}.$$

Now work done in adiabatic process
$$W = \frac{P_2 V_2 - P_1 V_1}{\gamma - 1} = \frac{(2.8 \times 10^6 \times 0.5) - (4 \times 10^5 \times 2)}{1.4 - 1} = 1.48 \times 10^6 \, J.$$

Work done in isothermal process W = 2.3026RT
$$\log \frac{V_2}{V_1}$$
 = 2.3026P₁V₁ $\log \frac{V_2}{V_1}$

$$= 2.3026 \times 4 \times 10^{5} \times 2 \times \log \left[\frac{0.5}{2.0} \right] = 2.3026 \times 4 \times 10^{5} \times 2 \log \left(\frac{1}{4} \right) = -1.1 \times 10^{6} \,\mathrm{J}$$

- Two samples of a gas initially at same temperature and pressure are compressed from a volume V to $\frac{V}{2}$. One sample is compressed isothermally and the other adiabatically. In which sample is the pressure greater?
- **Sol.** Let initial volume, $V_1 = V$ and pressure, $P_1 = P$, final volume, $V_2 = \frac{V}{2}$ and final pressure, $P_2 = \frac{V}{2}$

For isothermal compression
$$P_2V_2 = P_1V_1$$
 or $P_2 = \frac{P_1V_1}{V_2} = \frac{PV}{\frac{V}{2}} = 2P$

For adiabatic compression
$$P_2' = P_1 \left[\frac{V_1}{V_2} \right]^{\gamma} \Rightarrow P_2' = P \left[\frac{V}{V/2} \right]^{\gamma} = 2^{\gamma} P$$

$$\Rightarrow$$
 $P_2' = 2^{\gamma}P \quad \gamma > 1 :: 2^{\gamma} > 2 \text{ and } P_2' > P_2$

 \Rightarrow P₂' = 2^{\gamma}P \gamma > 1 \therefore 2^\gamma > 2 and P₂' > P₂
Pressure during adiabatic compression is greater than the pressure during isothermal compression.

Calculate the work done when 1 mole of a perfect gas is compressed adiabatically. The initial pressure and volume of the gas are 10⁵ N/m² and 6 litre respectively. The final volume of the gas is 2 liters.

Molar specific heat of the gas at constant volume is $\frac{3R}{2}$ [(3)^{5/3} = 6.19]

Sol. For an adiabatic change $PV^{\gamma} = \text{constant } P_1 V_1^{\gamma} = P_2 V_2^{\gamma}$

As molar specific heat of gas at constant volume $C_v = \frac{3}{2}R$

$$C_{p} = C_{V} + R = \frac{3}{2}R + R = \frac{5}{2}R \Rightarrow \gamma = \frac{C_{p}}{C_{V}} = \frac{\frac{5}{2}R}{\frac{3}{2}R} = \frac{5}{3}$$

E

$$P_2 = \left[\frac{V_1}{V_2}\right]^{\gamma} P_1 = \left[\frac{6}{2}\right]^{5/3} \times 10^5 = (3)^{5/3} \times 10^5 = 6.19 \times 10^5 \text{ N/m}^2$$

Work done
$$W = \frac{1}{1 - \gamma} [P_2 V_2 - P_1 V_1] = \frac{1}{1 - (5/3)} [6.19 \times 10^5 \times 2 \times 10^{-3} - 10^{-5} \times 6 \times 10^{-3}]$$

= $-\left[\frac{2 \times 10^2 \times 3}{2} (6.19 - 3)\right] = -3 \times 10^2 \times 3.19 = -957$ joules

- ive sign shows external work done on the gas

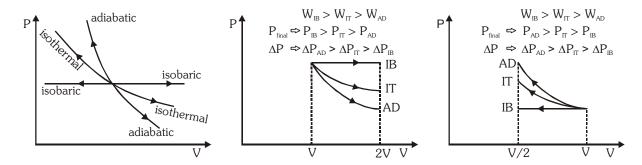
Ex. A motor tyre pumped to a pressure of 3 atm. It suddenly bursts. Calculate the fall in temperature due to adiabatic expansion. The temperature of air before expansion is 27° C. Given $\gamma=1.4$.

Sol. We know that
$$T_2^{\gamma} P_2^{1-\gamma} = T_1^{\gamma} P_1^{1-\gamma} \Rightarrow \left[\frac{T_2}{T_1} \right]^{\gamma} = \left[\frac{P_1}{P_2} \right]^{1-\gamma} \Rightarrow \left[\frac{T_2}{300} \right]^{1.4} = \left[\frac{3}{1} \right]^{1-1.4}$$

$$\Rightarrow \left[\frac{T_2}{300}\right]^{1.4} = \left[\frac{1}{3}\right]^{0.4} \Rightarrow T_2 = 219.2 \text{ K} \Rightarrow T_1 - T_2 = (300 - 219.2) \text{ K} = 80.8 \text{ K}$$

GOLDEN KEY POINT

When a gas expands its volume increases, then final pressure is less for adiabatic expansion. But, when
a gas compresses its volume decreases, then the final pressure is more in case of adiabatic compression.

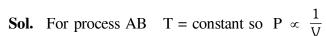


First Law of Thermodynamics Applied to Different Processes

Process	Q	ΔU	W	
Cyclic	W	0	Area of the closed curve	
Isochoric	ΔU	$\mu C_{\nu} \Delta T$ (μ mole of gas)	0	
Isothermal	W	0	$\mu RT log_{e} \left[\frac{V_{f}}{V_{i}} \right] = \mu RT log_{e} \left[\frac{P_{i}}{P_{f}} \right]$	
Adiabatic	0	–W	$\frac{\mu R(T_f - T_i)}{1 - \gamma}$	
Isobaric	$\mu C_P \Delta T$	$\mu C_{V}\Delta T$	$P(V_f - V_i) = \mu R(T_f - T_i)$	

Ex. Plot P - V, V - T graph corresponding to the P-T graph for an ideal

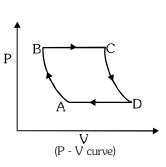
gas shown in figure. Explain your answers.

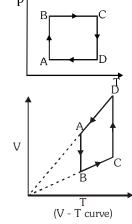


For process BC
$$P = constant$$
 so $V \propto T$

For process CD T = constant so V
$$\propto \frac{1}{P}$$

For process DA P = constant so $V \propto T$

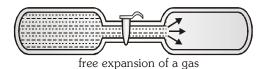




FREE EXPANSION

Take a thermally insulated bottle with ideal gas at some temperature T_1 and, by means of a pipe with a stopcock, connect this to another insulated bottle which is evacuated. If we suddenly open the stopcock, the gas will rush from the first bottle into the second until the pressures are equalized.

Experimentally, we find that this process of free expansion does not change the temperature of the gas – when the gas attains equilibrium and stops flowing, the final temperature of both botles are equal to the initial temperature T_1 .



This process is called a free expansion.

The change in the internal energy of the gas can be calculated by applying the first law of thermodynamics to the free–expansion process.

The process is adiabatic because of the insulation, So Q = 0.

No part of the surroundings moves so the system does no work on its surroundings.

• For ideal gas

$$(\delta W)_{ext.}$$
 = Work done against external atmosphere
= P dV = 0 (because P = 0)

 $(\delta W)_{int}$ = Work done against internal molucular forces = 0

$$\delta Q = dU + \delta W$$
 \Rightarrow $0 = dU + 0$

The internal energy does not change dU = 0 So U and T are constant.

The initial and final states of this gas have the same internal energy.

Which implies that the internal energy of an ideal gas does not depend on the volume at all.

The free-expansion process has led us to the following conclusion:

The internal energy U(T) of an ideal gas depends only on the temperature.

For real gas

In free expansion of real gases, measurements show that the temperature changes slightly in a free expansion. Which implies that the internal energy of a real gas depends on the volume also.

$$\delta Q = 0 \quad (\delta W)_{ext} = 0 \quad (: P = 0)$$

 $(\delta W)_{int} \neq 0$ (Intermolucular forces are present in real gases)

$$\delta Q = dU + \delta W \implies 0 = dU + (\delta W)_{int.} \Rightarrow dU = -(\delta W)_{int.}$$

⇒ U decreases. So T decreases.

E

RELATION BETWEEN DEGREE OF FREEDOM AND SPECIFIC HEAT OF GAS

Energy related with each degree of freedom = $\frac{1}{2}$ kT , Energy related with all degree of freedom = $\frac{f}{2}$ kT

Internal energy of one mole of ideal gas (total K.E.) $U = \frac{f}{2}RT$ for Isometric process (volume constant) $\delta W = 0$

By first law of thermodynamics $\delta Q = \delta W + dU \implies C_v dT = dU \implies C_v = \frac{dU}{dT}$

$$\begin{split} C_V = \frac{dU}{dT} = \frac{f}{2}R = \frac{R}{\gamma - 1} \quad . & C_P = C_V + R = \left[\frac{f}{2} + 1\right]R = \frac{\gamma R}{\gamma - 1} \quad and \quad \gamma = \frac{C_P}{C_V} = 1 + \frac{2}{f} \\ C_V = \frac{R}{\gamma - 1} \quad , \qquad C_P = \frac{\gamma R}{\gamma - 1} \quad and \quad \gamma = 1 + \frac{2}{f} \end{split}$$

General expression for C (C_p or C_v) in the process PV^x = constant $C = \frac{R}{\gamma - 1} + \frac{R}{1 - x}$

For isobaric process P = constant so x = 0 $\therefore C = C_P = \frac{R}{v - 1} + R = C_v + R$

For isothermal process, PV = constant so x = 1 \therefore $C = \infty$ For adiabatic process PV = constant so $x = \gamma$ \therefore C = 0

Values of f, U, C_v , C_p and γ for different gases are shown in table below.

Atomicity of gas		$C_{\mathbf{v}}$	Cp	γ
Monoatomic	3	$\frac{3}{2}$ R	$\frac{5}{2}$ R	$\frac{5}{3} = 1.67$
Diatomic	5	$\frac{5}{2}$ R	$\frac{7}{2}$ R	$\frac{7}{5} = 1.4$
Triatomic and Triatomic linear	7	$\frac{7}{2}$ R	$\frac{9}{2}$ R	$\frac{9}{7} = 1.28$
Poly atomic Triangular Non-linear	6	$\frac{6}{2}$ R = 3R	$\frac{8}{2}$ R = 4R	$\frac{4}{3} = 1.33$

- $1 < \gamma < 2$
- If atomicity of gases is same U, C_p , C_v and γ is same for gas mixture.
- If in a gas mixture gases are of different atomicity, then for gas mixture γ changes according to following condition. Diatomic $\gamma_1 \le \text{mixture} \le \gamma_2$ mono atomic where $\gamma_1 < \gamma_2$
- If 'f' is the degree of freedom per molecule for a gas, then

Total energy of each molecule = $\frac{fkT}{2}$

Total energy per mole of gas = $N_0 \frac{f}{2}kT = \frac{f}{2}RT$



• According to kinetic theory of gases, the molecule are not interacting with each other. So potential energy is zero and internal energy of gas molecules is only their kinetic energy.

- For ' μ ' mole of a gas : Internal energy at temperature T is $U = \frac{\mu f R T}{2} = \mu C_v T$
- Change in internal energy is given by $dU = \frac{\mu fR}{2}(dT) = \mu C_V dT$ This change is process independent.

C_p is greater than C_v

If a gas is heated at constant volume, the gas does no work against external pressure. In this case, the whole of the heat energy supplied to the gas is spend in raising the temperature of the gas.

If a gas is heated at constant pressure, its volume increases. In this case, heat energy is required for the following two purpose:

- (i) To increase the volume of the gas against external pressure.
- (ii) To increase the temperature of 1 mole of gas through 1 K.

Thus, more heat energy is required to raise the temperature of 1 mole of gas through 1 K when it is heated at constant pressure than when it is heated at constant volume. \therefore $C_p > C_v$

The difference between C_p and C_v is equal to thermal equivalent of the work done by the gas in expanding against external pressure.

Mayor's formula: $C_p - C_v = R$

: At constant pressure $dQ = \mu C_p dT$, $dU = \mu C_v dT$ & $dW = PdV = \mu RdT$

Now from first law of thermodynamics dQ = dW + dU

$$\Rightarrow \mu C_p dT = \mu R dT + \mu C_v dT \Rightarrow C_p = R + C_v \Rightarrow C_p - C_v = R$$

- Ex. Calculate the difference between two specific heats of 1 g of helium gas at NTP. Molecular weight of helium = 4 and J = 4.186×10^7 erg cal⁻¹.
- **Sol.** Gas constant for 1 g of helium, $r = \frac{R}{M_w} = \frac{PV}{T \times M_w} = \frac{76 \times 13.6 \times 981 \times 22400}{273 \times 4} = 2.08 \times 10^7 \text{ erg g}^{-1} \text{ K}^{-1}$

$$C_P - C_V = \frac{r}{J} = \frac{2.08 \times 10^7}{4.186 \times 10^7} = 0.5 \text{ cal } g^{-1} \text{ K}^{-1}$$

- Ex. Calculate the molar specific heat at constant volume. Given: specific heat of hydrogen at constant pressure is 6.85 cal mol⁻¹ K⁻¹ and density of hydrogen = 0.0899 g cm⁻³. One mole of gas = 2.016 g, J = 4.2×10^7 erg cal⁻¹ and 1 atmosphere = 10^6 dyne cm⁻².
- **Sol.** Since the density of hydrogen is 0.0899 g cm⁻³ therefore volume occupied by 0.0899 g of hydrogen

at NTP is 1000 cm³. So, volume of 1 mole (2.016 g) of gas, $V = \frac{1000}{0.0899} \times 2.016 \text{ cm}^3$

$$C_{_{P}}-C_{_{V}}=\frac{R}{J}=\frac{PV}{T\times J}=\frac{10^{6}\times 1000\times 2.016}{0.0899\times 273\times 4.2\times 10^{7}}=1.96~cal~mol^{-1}~K^{-1}$$

$$\therefore C_v = C_p - 1.96 = (6.85 - 1.96) = 4.89 \text{ cal mol}^{-1} \text{ K}^{-1}$$

E

Ex. The specific heat of argon at constant volume is 0.075 kcal/kg K. Calculate its atomic weight, $[R = 2cal/mol \ K]$

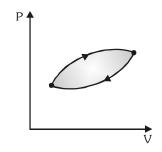
Sol. As argon is monoatomic, its molar specific heat at constant volume will be

$$C_v = \frac{3}{2}R = \frac{3}{2} \times 2 = 3$$
 cal/mol K, $C_v = M_w c_v$ and $c_v = 0.075$ cal/g K

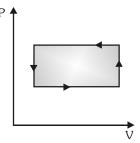
So
$$3 = M_w \times 0.075 \implies M_w = \frac{3}{0.075} = 40 \text{ gram/mole}$$

Cyclic process

Cyclic process is that thermodynamic process in which the system returns to its initial stage after undergoing a series of changes. A typical cyclic process is represented on PV diagram as shown in figure.

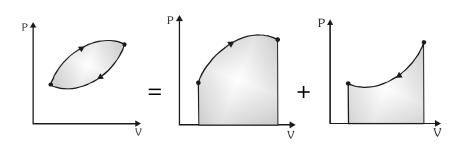


 $W_{clockwise cycle} = + Shaded area$



 $W_{anticlockwise cycle} = -$ Shaded area

WORK DONE IN CLOCKWISE CYCLE



W_{AB I} Positive

$$W_{\text{cyclic}} = W_{\text{AB I}}(\text{positive}) + W_{\text{AB II}}$$

W_{AB II} Negative

$$(\text{negative}) = \int_{\text{dosed Path}}^{\text{drea of Path}} ds$$

Similarly work done in anticlociwise cyclic process is negative.

CARNOT CYCLE

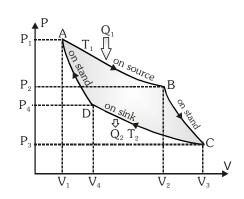
Carnot devised an ideal engine which is based on a reversible cycle of four operations in succession :

(i) isothermal expansion, $A \rightarrow B$

(ii) adiabatic expansion, $B \rightarrow C$

(iii) isothermal compression $C \rightarrow D$

(iv) adiabatic compression. $D \rightarrow A$

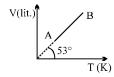


1/10,10,100,245/DIPDeb/nods06/2020-21(B0B0 BA) Vison VIEEA dvanced (Woodule Coding IV-Tag) VLeaden VPhysias VThermal Physias VEnglish VO3_KTG & Thermachyp65

ALLEN

EXERCISE (S)

1. V-T curve for 2 moles of a gas is straight line as shown in the graph here. Find the pressure of gas at A.



KT0001

2. An empty pressure cooker of volume 10 litres contains air at atmospheric pressure 10⁵ Pa and temperature of 27°C. It contains a whistle which has area of 0.1 cm² and weight of 100 g. What should be the temperature of air inside so that the whistle is just lifted up?



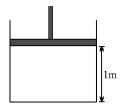
KT0002

3. Find the molecular mass of a gas if the specific heats of the gas are $C_p = 0.2$ cal/gm°C and $C_V = 0.15$ cal/gm°C. [Take R = 2 cal/mole°C]

KT0004

4. The piston cylinder arrangement shown contains a diatomic gas at temperature 300 K. The cross-sectional area of the cylinder is 1 m². Initially the height of the piston above the base of the cylinder is 1 m. The temperature is now raised to 400 K at constant pressure. Find the new height of the piston above the base of the cylinder. If the piston is now brought back to its original height without any heat loss, find the new equilibrium temperature of the gas. You can leave the answer in fraction.

[JEE' 2004]



KT0005

5. A mixture of 4 gm helium and 28 gm of nitrogen is enclosed in a vessel of constant volume 300 K. Find the quantity of heat absorbed by the mixture to doubled the root mean velocity of its molecules. (R = Universal gas constant)

6. An insulated container containing monoatomic gas of molar mass m is moving with a velocity v_0 . If the container is suddenly stopped, find the change in temperature. [JEE 2003]

KT0007

7. If heat is added at constant volume, 6300 J of heat are required to raise the temperature of an ideal gas by 150 K. If instead, heat is added at constant pressure, 8800 joules are required for the same temperature change. When the temperature of the gas changes by 300 K, determine the change is the internal energy of the gas.

KT0008

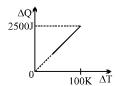
8. Ideal diatomic gas is taken through a process $\Delta Q = 2\Delta U$. Find the molar heat capacity for the process (where ΔQ is the heat supplied and ΔU is change in internal energy)

KT0009

9. A cylinder with a movable piston contains 3 moles of hydrogen at standard temperature and pressure. The walls of the cylinder are made of a heat insulator, and the piston is insulated by having a pile of sand on it. By what factor does the pressure of the gas increase if the gas is compressed to half its original volume?

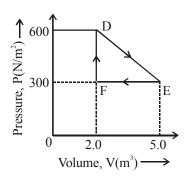
KT0010

10. One mole of a gas mixture is heated under constant pressure, and heat required ΔQ is plotted against temperature difference acquired. Find the value of γ for mixture.



KT0011

11. A thermodynamic system is taken from an original state to an intermediate state by the linear process shown in figure. Its volume is then reduced to the original value from E to F by an isobaric process. Calculate the total work done by the gas from D to E to F



KT0012

12. In changing the state of a gas adiabatically from an equilibrium state A to another equilibrium state B, an amount of work equal to 22.3 J is done on the system. If the gas is taken from state A to B via a process in which the net heat absorbed by the system is 9.35 cal, how much is the net work done by the system in the latter case ? (Take 1 cal = 4.19 J)

13. One mole of an ideal monoatomic gas undergoes a process as shown in the figure. Find the molar specific heat of the gas in the process.



KT0014

- **14.** Two cylinders A and B of equal capacity are connected to each other via a stopcock. A contains a gas at standard temperature and pressure. B is completely evacuated. The entire system is thermally insulated. The stopcock is suddenly opened. Answer the following:
 - (a) What is the final pressure of the gas in A and B?
 - (b) What is the change in internal energy of the gas?
 - (c) What is the change in the temperature of the gas?
 - (d) Do the intermediate states of the system (before settling to the final equilibrium state) lie on its P-V-T surface ?

KTG

EXERCISE (O)

SINGLE CORRECT TYPE QUESTIONS

1.	Find the approx. number of molecules contained in a vessel of volume 7 litres at 0° C at 1.3×10^{5}				
	pascal				
	(A) 2.4×10^{23}	(B) 3×10^{23}	(C) 6×10^{23}	(D) 4.8×10^{23}	

2. An ideal gas mixture filled inside a balloon expands according to the relation $PV^{2/3}$ = constant. The temperature inside the balloon is

(A) increasing

(B) decreasing

(C) constant

(D) can't be said

KT0030

KT0029

3. At a temperature T K, the pressure of 4.0g argon in a bulb is p. The bulb is put in a bath having temperature higher by 50K than the first one. 0.8g of argon gas had to be removed to maintained original pressure. The temperature T is equal to

(A) 510 K

(B) 200 K

(C) 100 K

(D) 73 K

KT0031

28 gm of N_2 gas is contained in a flask at a pressure of 10 atm and at a temperature of 57°. It is found that due to leakage in the flask, the pressure is reduced to half and the temperature reduced to 27°C. The quantity of N_2 gas that leaked out is:-

(A) 11/20 gm

(B) 20/11 gm

(C) 5/63 gm

(D) 63/5 gm

KT0032

A container X has volume double that of container Y and both are connected by a thin tube. Both contains same ideal gas. The temperature of X is 200K and that of Y is 400K. If mass of gas in X is m then in Y it will be:

(A) m/8

(B) m/6

(C) m/4

(D) m/2

KT0033

6. When 2 gms of a gas are introduced into an evacuated flask kept at 25°C the pressure is found to be one atmosphere. If 3 gms of another gas added to the same flask the pressure becomes 1.5 atmospheres. The ratio of the molecular weights of these gases will be:-

(A) 1:3

(B) 3:1

(C) 2:3

(D) 3:2

KT0034

7. A rigid tank contains 35 kg of nitrogen at 6 atm. Sufficient quantity of oxygen is supplied to increase the pressure to 9 atm, while the temperature remains constant. Amount of oxygen supplied to the tank is:

(A) 5 kg

(B) 10 kg

(C) 20 kg

(D) 40 kg

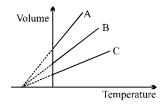
- 8. During an experiment an ideal gas obeys an addition equation of state $P^2V = constant$. The initial temperature and pressure of gas are T and V respectively. When it expands to volume 2V, then its temperature will be:
 - (A) T
- (B) $\sqrt{2}$ T
- (C) 2 T
- (D) $2\sqrt{2}$ T

KT0036

- 9. A vessel contains 1 mole of O₂ gas (molar mass 32) at a temperature T. The pressure of the gas is P. An identical vessel containing one mole of He gas (molar mass 4) at a temperature 2T has a pressure of
 - (A) P/8
- (B) P
- (C) 2P
- (D) 8P

KT0037

10. The expansion of an ideal gas of mass m at a constant pressure P is given by the straight line B. Then the expansion of the same ideal gas of mass 2 m at a pressure 2P is given by the straight line



- (A) C
- (B) A
- (C) B
- (D) none

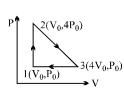
KT0038

11. A cylindrical tube of cross-sectional area A has two air tight frictionless pistons at its two ends. The pistons are tied with a straight piece of metallic wire. The tube contains a gas at atmospheric pressure P_0 and temperature T_0 . If temperature of the gas is doubled then the tension in the wire is



- $(A) 4 P_0 A$
- (B) $P_0 A/2$
- $(C) P_0 A$
- (D) $2 P_0 A$

- 12. One mole of an ideal diatomic gas is taken through the cycle as shown in the figure.
 - $1 \rightarrow 2$: isochoric process
 - $2 \rightarrow 3$: straight line on P-V diagram
 - $3 \rightarrow 1$: isobaric process
 - The average molecular speed of the gas in the states 1, 2 and 3 are in the ratio



- (A) 1:2:2
- (B) $1:\sqrt{2}:\sqrt{2}$
- (C) 1:1:1
- (D) 1:2:4

13.	One mole of an ideal gas at STP is heated in an insulated closed container until the average speed of
	its molecules is doubled. Its pressure would therefore increase by factor.

- (A) 1.5
- (B) $\sqrt{2}$
- (C)2

(D) 4

KT0041

14. Three particles have speeds of 2u, 10u and 11u. Which of the following statements is correct?

- (A) The r.m.s. speed exceeds the mean speed by about u.
- (B) The mean speed exceeds the r.m.s. speed by about u.
- (C) The r.m.s. speed equals the mean speed.
- (D) The r.m.s. speed exceeds the mean speed by more than 2u.

KT0042

15. One mole of an ideal gas is contained with in a cylinder by a frictionless piston and is initially at temperature T. The pressure of the gas is kept constant while it is heated and its volume doubles. If R is molar gas constant, the work done by the gas in increasing its volume is:-

- (A) RT *l*n2
- (B) 1/2 RT
- (C) RT
- (D) 3/2 RT

KT0043

16. A gas mixture consists of 2 moles of oxygen and 4 moles of argon at temperature T. Neglecting all vibrational modes, the total internal energy of the system is :-

- (A) 4 RT
- (B) 15 RT
- (C) 9 RT
- (D) 11 RT

KT0044

First Law of Thermodynamics:

17. In thermodynamic process pressure of a fixed mass of gas is changed in such a manner that the gas releases 30 joule of heat and 18 joule of work was done on the gas. If the initial internal energy of the gas was 60 joule, then, the final internal energy will be:

(A) 32 joule

(B) 48 joule

(C) 72 joule

(D) 96 joule

KT0045

18. Two monoatomic ideal gas at temperature T_1 and T_2 are mixed. There is no loss of energy. If the masses of molecules of the two gases are m_1 and m_2 and number of their molecules are n_1 and n_2 respectively. The temperature of the mixture will be:

(A)
$$\frac{T_1 + T_2}{n_1 + n_2}$$

(B)
$$\frac{T_1}{n_1} + \frac{T_2}{n_2}$$

(C)
$$\frac{n_2 T_1 + n_1 T_2}{n_1 + n_2}$$

(D)
$$\frac{n_1 T_1 + n_2 T_2}{n_1 + n_2}$$

KT0046

19. An ideal gas expands isothermally from a volume V_1 to V_2 and then compressed to original volume V_1 adiabatically. Initial pressure is P_1 and final pressure is P_3 . The total work done is W. Then

[JEE' 2004 (Scr)]

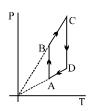
(A)
$$P_3 > P_1, W > 0$$

(B)
$$P_3 < P_1$$
, $W < 0$

(C)
$$P_3 > P_1$$
, W < 0

(D)
$$P_3 = P_1$$
, $W = 0$

20. Pressure versus temperature graph of an ideal gas is shown in figure



- (A) During the process AB work done by the gas is positive
- (B) During the process CD work done by the gas is negative
- (C) During the process BC internal energy of the gas is increasing
- (D) None

KT0048

- A polyatomic gas with six degrees of freedom does 25J of work when it is expanded at constant 21. pressure. The heat given to the gas is :-
 - (A) 100J
- (B) 150J
- (C) 200J
- (D) 250J

KT0049

- A reversible adiabatic path on a P-V diagram for an ideal gas passes through state A where 22. $P = 0.7 \times 10^5 \text{ N/m}^{-2}$ and $V = 0.0049 \text{ m}^3$. The ratio of specific heat of the gas is 1.4. The slope of path at A is:
 - (A) $2.0 \times 10^7 \text{ Nm}^{-5}$

(B) $1.0 \times 10^7 \text{ Nm}^{-5}$

 $(C) - 2.0 \times 10^7 \text{ Nm}^{-5}$

(D) $-1.0 \times 10^7 \text{ Nm}^{-5}$

KT0050

- 23. The adiabatic Bulk modulus of a diatomic gas at atmospheric pressure is
 - $(A) 0 \text{ Nm}^{-2}$
- (B) 1 Nm^{-2}
- (C) $1.4 \times 10^4 \text{ Nm}^{-2}$
- (D) $1.4 \times 10^5 \,\text{Nm}^{-2}$

KT0051

- A given quantity of an ideal gas is at pressure P and absolute temperature T. The isothermal bulk 24. modulus of the gas is:
 - (A) 2P/3
- (B) P
- (C) 3P/2
- (D) 2P

KT0052

One mole of an ideal gas at temperature T_1 expends according to the law $\frac{P}{V^2}$ = a (constant). The **25.**

work done by the gas till temperature of gas becomes T₂ is:

- (A) $\frac{1}{2}R(T_2 T_1)$ (B) $\frac{1}{3}R(T_2 T_1)$ (C) $\frac{1}{4}R(T_2 T_1)$ (D) $\frac{1}{5}R(T_2 T_1)$

- **26.** The first law of thermodynamics can be written as $\Delta U = \Delta Q + \Delta W$ for an ideal gas. Which of the following statements is correct?
 - (A) ΔU is always zero when no heat enters or leaves the gas
 - (B) ΔW is the work done by the gas in this written law.
 - (C) ΔU is zero when heat is supplied and the temperature stays constant
 - (D) $\Delta Q = -\Delta W$ when the temperature increases very slowly.

KT0054

27. 2 moles of a monoatomic gas are expanded to double its initial volume, through a process P/V = constant. If its initial temperature is 300 K, then which of the following is not true.

(A)
$$\Delta T = 900 \text{ K}$$

(B)
$$\Delta Q = 3200 \text{ R}$$

(C)
$$\Delta Q = 3600 \text{ R}$$

(D)
$$W = 900 R$$

KT0055

28. A student records ΔQ , ΔU & ΔW for a thermodynamic cycle $A \rightarrow B \rightarrow C \rightarrow A$. Certain entries are missing. Find correct entry in following options.

	AB	BC	CA
ΔW	40J		30J
ΔU		50J	
ΔQ	150J	10J	

(A)
$$W_{BC} = -70 \text{ J}$$

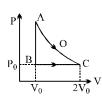
(B)
$$\Delta Q_{CA} = 130 \text{ J}$$

(C)
$$\Delta U_{AB} = 190 \text{ J}$$

(D)
$$\Delta U_{C_{\Delta}} = -160 \text{ J}$$

KT0056

29. An ideal gas is taken from point A to point C on P-V diagram through two process AOC and ABC as shown in the figure. Process AOC is isothermal

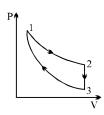


- (A) Process AOC requires more heat than process ABC.
- (B) Process ABC requires more heat than process AOC.
- (C) Both process AOC & ABC require same amount of heat.
- (D) Data is insufficient for comparison of heat requirement for the two processes.

KT0058

- **30.** Monoatomic, diatomic and triatomic gases whose initial volume and pressure are same, are compressed till their volume becomes half the initial volume.
 - (A) If the compression is adiabatic then monoatomic gas will have maximum final pressure.
 - (B) If the compression is adiabatic then triatomic gas will have maximum final pressure.
 - (C) If the compression is adiabatic then their final pressure will be same.
 - (D) If the compression is isothermal then their final pressure will be different.

31. Three processes form a thermodynamic cycle as shown on P-V diagram for an ideal gas. Process $1 \rightarrow 2$ takes place at constant temperature (300K). Process $2 \rightarrow 3$ takes place at constant volume. During this process 40J of heat leaves the system. Process $3 \rightarrow 1$ is adiabatic and temperature T_3 is 275K. Work done by the gas during the process $3 \rightarrow 1$ is:-



- (A) 40J
- (B) 20J
- (C) + 40J
- (D) + 20J

KT0060

32. A closed container is fully insulated from outside. One half of it is filled with an ideal gas X separated by a plate P from the other half Y which contains a vacuum as shown in figure. When P is removed, X moves into Y. Which of the following statements is correct?

X	Y
gas	vacuum
p	

(A) No work is done by X

- (B) X decreases in temperature
- (C) X increases in internal energy
- (D) X doubles in pressure

KT0061

33. Water is heated in an open pan where the air pressure is 10^{+5} Pa. The water remains a liquid, which expands by a small amount as it is heated. Determine the ratio of the heat absorbed by the water to the work done by water. (γ for water = 10^{-3} /C, S = 1 cal/gm°C)

(A)
$$4.2 \times 10^3$$

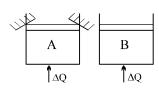
(B)
$$4.2 \times 10^5$$

(C)
$$4.2 \times 10^2$$

(D)
$$4.2 \times 10^4$$

KT0062

34. Two identical vessels A & B contain equal amount of ideal monoatomic gas. The piston of A is fixed but that of B is free. Same amount of heat is absorbed by A & B. If B's internal energy increases by 100 J the change in internal energy of A is:-



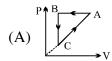
- (A) 100 J
- (B) $\frac{500}{3}$ J
- (C) 250 J
- (D) none of these

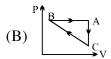
- An ideal gas expands from volume V₁ to V₂. This may be achieved by either of the three processes: **35.** isobaric, isothermal and adiabatic. Let ΔU be the change in internal energy of the gas, Q be the quantity of heat added to the system and W be the work done by the gas. Identify which of the following statements is false for ΔU ?
 - (A) ΔU is least under adiabatic process.
 - (B) ΔU is greatest under adiabatic process.
 - (C) ΔU is greatest under the isobaric process.

KT0064

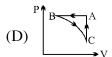
- (D) ΔU in isothermal process lies in-between the values obtained under isobaric and adiabatic processes.
- **36.** A cyclic process ABCA is shown in PT diagram. When presented on PV, it would







$$(C) \xrightarrow{P} \xrightarrow{B} \xrightarrow{A}$$



KT0065

- During an adiabatic process, the pressure of a gas is found to be proportional to the cube of its **37.** absolute temperature. The ratio C_p/C_v for the gas is-[AIEEE - 2003]
 - (A) 4/3
- (B)2

- (C) 5/3
- (D) 3/2

KT0067

MULTIPLE CORRECT TYPE QUESTIONS

- 38. Two gases have the same initial pressure, volume and temperature. They expand to the same final volume, one adiabatically and the other isothermally
 - (A) The final temperature is greater for the isothermal process
 - (B) The final pressure is greater for the isothermal process
 - (C) The work done by the gas is greater for the isothermal process
 - (D) All the above options are incorrect

KT0070

- **39.** On the P-T graph of an ideal gas,
 - (A) adiabatic process will be a straight line
 - (B) isochoric process will be a straight line passing through the origin
 - (C) adiabatic curve will have a positive slope
 - (D) the slope of adiabatic curve will decrease with increase in T

KT0071

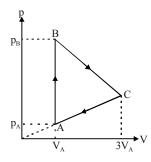
\\10.10.100.245\DTPDda\vaole06\2020-21[9080-BA]\Xcav\UEEAdvaraas|\WoduleCoding|V-Tag|\Uacder\Physis\Themud Physis\English\03_KTG & Themody p65

- 40. During the melting of a slab of ice at 273 K at atmospheric pressure
 - (A) Positive work is done by the ice-water system on the atmosphere
 - (B) Positive work is done on the ice-water system by the atmosphere
 - (C) The internal energy of the ice-water increases
 - (D) The internal energy of ice-water system decreases

KT0072

Paragraph for question nos. 41 and 42

A sample of ideal gas is taken through the cyclic process shown in the figure. The temperature of the gas at state A is $T_A = 200 \text{ K}$. At states B and C the temperature of the gas is the same.



41. Net work done by the gas in the process is

(A)
$$2P_AV_A$$

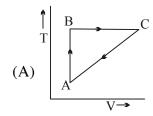
(B)
$$4P_AV_A$$

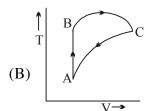
$$(C) 6P_AV_A$$

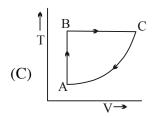
(D)
$$8P_AV_A$$

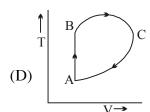
KT0073

42. Which of the following graphs best represent the cyclic process in T-V diagram.



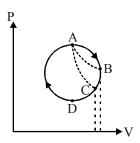






MATRIX MATCH TYPE

43. For an ideal gas a process PV diagram is a circle. An adiabatic from A passes through C. An isotherm from A passes through B. We take a part of the circular cyclic process. Comment on the sign of the quantity of column-I.



Column-I

- (A) Heat given to the gas in going from A to C along circle
- (B) Heat given to the gas in going from B to C along circle
- (C) Heat given to the gas in going from C to D along circle

Column-II

- (P) Positive
- (Q) Negative
- (R) Zero
- (S) can't be said

If S is stress and Y is Young's modulus of material of a wire, the energy stored in the wire per unit 1. volume is-[AIEEE - 2005]

 $(1) 2S^2Y$

(2) $\frac{S^2}{2Y}$ (3) $\frac{2Y}{S^2}$

 $(4) \frac{S}{2V}$

EH0162

2. A wire elongates by ℓ mm when a load W is hanged from it. If the wire goes over a pulley and two weights W each are hung at the two ends, the elongation of the wire will be (in mm)-

[AIEEE - 2006]

 $(1) \ell$

 $(2) 2\ell$

(3) zero

(4) $\ell/2$

EH0163

3. An insulated container of gas has two chambers separated by an insulating partition. One of the chambers has volume V₁ and contains ideal gas at pressure P₁ and temperature T₁. The other chamber has volume V₂ and contains ideal gas at pressure P₂ and tempeature T₂. If the partition is removed without doing any work on the gas, the final equilibrium temperature of the gas in the container will be-[AIEEE-2008]

 $(1) \quad \frac{T_1 T_2 \left(P_1 V_1 + P_2 V_2 \right)}{P_1 V_1 T_2 + P_2 V_2 T_1} \quad (2) \quad \frac{P_1 V_1 T_1 + P_2 V_2 T_2}{P_1 V_1 + P_2 V_2} \qquad (3) \quad \frac{P_1 V_1 T_2 + P_2 V_2 T_1}{P_1 V_1 + P_2 V_2} \qquad (4) \quad \frac{T_1 T_2 \left(P_1 V_1 + P_2 V_2 \right)}{P_1 V_1 T_1 + P_2 V_2 T_2}$

KT0146

One kg of a diatomic gas is at a pressure of 8×10^4 N/m². The density of the gas is 4 kg/m³. What is 4. the energy of the gas due to its thermal motion? [AIEEE-2009]

 $(1) 6 \times 10^4 \text{ J}$

 $(2) 7 \times 10^4 \text{ J}$

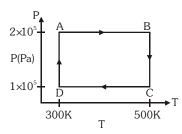
 $(3) 3 \times 10^4 \text{ J}$

 $(4) 5 \times 10^4 \text{ J}$

KT0097

Directions: Question number 5, 6 and 7 are based on the following paragraph.

Two moles of helium gas are taken over the cycle ABCDA, as shown in the P-T diagram.



5. Assuming the gas to be ideal the work done on the gas in taking it from A to B is :- [AIEEE-2009]

(1) 400 R

(2) 500 R

(3) 200 R

(4)300

The work done on the gas in taking it from D to A is:-6.

[AIEEE-2009]

- (1) -690 R
- (2) +690 R
- (4) + 414 R

KT0099

7. The net work done on the gas in the cycle ABCDA is :- [AIEEE-2009]

- (1) 1076 R
- (2) 1904 R
- (3) Zero
- (4) 276 R

KT0100

- 8. Two wires are made of the same material and have the same volume. However wire 1 has crosssectional area A and wire 2 has cross-sectional area 3A. If the length of wire 1 increases by Δx on applying force F, how much force is needed to stretch wire 2 by the same amount ?[AIEEE-2009]
 - (1) 6F
- (2)9F
- (3) F
- (4)4F

EH0127

- 9. A diatomic ideal gas is used in a carnot engine as the working substance. If during the adiabatic expansion part of the cycle the volume of the gas increases from V to 32 V, the efficiency of the engine is :-[AIEEE-2010]
 - (1)0.25
- (2) 0.5
- (3) 0.75
- (4)0.99

KT0101

- **10.** Three perfect gases at absolute temperatures T₁, T₂ and T₃ are mixed. The masses of molecules are m_1 , m_2 , and m_3 and the number of molecules are n_1 , n_2 and n_3 respectively. Assuming no loss of energy, then final temperature of the mixture is:-[AIEEE-2011]
 - $(1) \ \frac{n_1 T_1^2 + n_2 T_2^2 + n_3 T_3^2}{n_1 T_1 + n_2 T_2 + n_3 T_3} \quad (2) \ \frac{n_1^2 T_1^2 + n_2^2 T_2^2 + n_3^2 T_3^2}{n_1 T_1 + n_2 T_2 + n_3 T_3} \quad (3) \ \frac{T_1 + T_2 + T_3}{3} \qquad \qquad (4) \ \frac{n_1 T_1 + n_2 T_2 + n_3 T_3}{n_1 + n_2 + n_3}$

KT0104

A container with insulating walls is divided into two equal parts by a partition fitted with a valve. One 11. part is filled with an ideal gas at a pressure P and temperature T, whereas the other part is completely evacuated. If the valve is suddenly opened, the pressure and temperature of the gas will be :-

[AIEEE-2011]

- $(1) \frac{P}{2}, T$
- $(2) \frac{P}{2}, \frac{T}{2}$
- (3) P, T
- (4) $P, \frac{T}{2}$

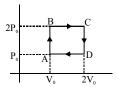
KT0106

- 100 g of water is heated from 30°C to 50°C Ignoring the slight expansion of the water, the change in **12.** its internal energy is (specific heat of water is 4184 J/kg/K):-[AIEEE - 2011]
 - (1) 84 kJ
- (2) 2.1 kJ
- (3) 4.2 kJ
- (4) 8.4 kJ

KT0147

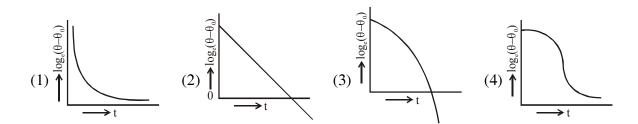
13. Helium gas goes through a cycle ABCDA (consisting of two isochoric and two isobaric lines) as shown in figure. Efficiency of this cycle is nearly (Assume the gas to be close to ideal gas):-

[AIEEE-2012]



- (1) 12.5%
- (2) 15.4%
- (3)9.1%
- (4) 10.5%

14. A liquid in a beaker has temperature $\theta(t)$ at time t and θ_0 is temperature of surroundings, then according to Newton's law of cooling the correct graph between $\log_e(\theta - \theta_0)$ and t is :- [AIEEE 2012]



EH0130

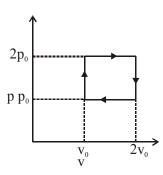
15. A wooden wheel of radius R is made of two semicircular parts (see figure). The two parts are held together by a ring made of a metal strip of cross sectional area S and Length L. L is slightly less than $2\pi R$. To fit the ring on the wheel, it is heated so that its temperature rises by ΔT and it just steps over the wheel. As it cools down to surrounding temperature, it presses the semicircular parts together. If the coefficient of linear expansion of the metal is α , and its Young's modulus is Y, the force that one part of the wheel applies on the other part is : [AIEEE 2012]



- (1) $2SY\alpha\Delta T$
- (2) $2 \pi SY\alpha\Delta T$
- (3) SΥαΔΤ
- (4) π SY $\alpha\Delta$ T

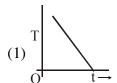
EH0131

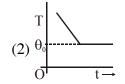
16. The above p-v diagram represents the thermodynamic cycle of an engine, operating with an ideal monoatomic gas. The amount of heat, extracted from the source in a single cycle is: [JEE-Mains-2013]

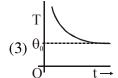


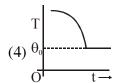
- $(1) p_0 v_0$
- $(2) \left(\frac{13}{2}\right) p_0 v_0$
- $(3) \left(\frac{11}{2}\right) p_0 v_0$
- $(4) 4p_0 v_0$

17. If a piece of metal is heated to temperature θ and then allowed to cool in a room which is at temperature θ_0 the graph between the temperature T of the metal and time t will be closed to: [JEE-Main-2013]









EH0132

18. An open glass tube is immersed in mercury in such a way that a length of 8 cm extends above the mercury level. The open of the tube is then closed and sealed and the tube is raised vertically up by addition 46 cm. What will be length of the air column above mercury in the tube now?

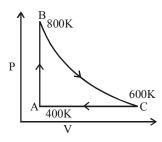
(Atmospheric pressure = 76 cm of Hg)

[**JEE-Mains-2014**]

- (1) 38 cm
- (2) 6 cm
- (3) 16 cm
- (4) 22 cm

KT0110

19. One mole of diatomic ideal gas undergoes a cyclic process ABC as shown in figure. The process BC is adiabatic. The temperatures at A, B and C are 400 K, 800 K and 600 K respectively. Choose the correct statement:



- (1) The change in internal energy in the process AB is -350 R.
- (2) The change in internal energy in the process BC is -500R
- (3) The change in internal energy in whole cyclic process is 250 R.
- (4) The change in internal energy in the process CA is 700 R.

KT0111

- 20. Three rods of Copper, Brass and Steel are welded together to form a Y-shaped structure. Area of cross-section of each rod = 4 cm². End of copper rod is maintained at 100°C where as ends of brass and steel are kept at 0°C. Lengths of the copper, brass and steel rods are 46, 13 and 12 cms respectively. The rods are thermally insulated from surroundings except at ends. Thermal conductivities of copper, brass and steel are 0.92, 0.26 and 0.12 CGS units respectively. Rate of heat flow through copper rod is:
 - (1) 4.8 cal/s
- (2) 6.0 cal/s
- (3) 1.2 cal/s
- (4) 2.4 cal/s

EH0134

21. The pressure that has to be applied to the ends of a steel wire of length 10 cm to keep its length constant when its temperature is raised by 100°C is: [JEE-Main-2014]

(For steel Young's modulus is 2×10^{11} N m⁻² and coefficient of thermal expansion is 1.1×10^{-5} K⁻¹)

- $(1) 2.2 \times 10^7 \text{ Pa}$
- $(2) 2.2 \times 10^6 \text{ Pa}$
- $(3) 2.2 \times 10^8 \text{ Pa}$
- $(4) 2.2 \times 10^9 \text{ Pa}$

ЕН0133

Consider a spherical shell of radius R at temperature T. The black body radiation inside it can be 22. considered as an ideal gas of photons with internal energy per unit volume $u = \frac{U}{V} \propto T^4$ and pressure $p = \frac{1}{3} \left(\frac{U}{V} \right)$. If the shell now undergoes an adiabatic expansion the relation between T and R is -

[**JEE-Mains-2015**]

(1) T
$$\propto \frac{1}{R}$$

$$(2) T \propto \frac{1}{R^3}$$

(3) T
$$\propto$$
 e^{-R}

(4) T
$$\propto$$
 e^{-3R}

KT0113

Consider an ideal gas confined in an isolated closed chamber. As the gas undergoes an adiabatic 23. expansion, the average time of collision between molecules increases as Vq, where V is the volume of

the gas. The value of q is :- $\left(\gamma = \frac{C_p}{C} \right)$

[JEE-Mains-2015]

$$(1) \ \frac{\gamma+1}{2}$$

$$(2) \frac{\gamma - 1}{2}$$

(2)
$$\frac{\gamma - 1}{2}$$
 (3) $\frac{3\gamma + 5}{6}$

$$(4) \frac{3\gamma - 5}{6}$$

KT0114

24. A pendulum made of a uniform wire of cross sectional area A has time period T. When an additional mass M is added to its bob, the time period changes to T_M. If the Young's modulus of the material of the wire is Y then $\frac{1}{Y}$ is equal to :- (g = gravitational acceleration) [JEE-Main-2015]

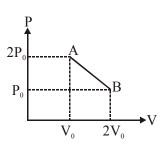
$$(1) \left[1 - \left(\frac{T_{\rm M}}{T} \right)^2 \right] \frac{A}{Mg}$$

$$(2) \left[1 - \left(\frac{T}{T_{\rm M}} \right)^2 \right] \frac{A}{Mg}$$

$$(3) \left[\left(\frac{T_{M}}{T} \right)^{2} - 1 \right] \frac{A}{Mg}$$

$$(1)\left[1-\left(\frac{T_{M}}{T}\right)^{2}\right]\frac{A}{Mg} \qquad (2)\left[1-\left(\frac{T}{T_{M}}\right)^{2}\right]\frac{A}{Mg} \qquad (3)\left[\left(\frac{T_{M}}{T}\right)^{2}-1\right]\frac{A}{Mg} \qquad (4)\left[\left(\frac{T_{M}}{T}\right)^{2}-1\right]\frac{Mg}{A}$$

'n' moles of an ideal gas undergoes a process $A \rightarrow B$ as shown in the figure. The maximum temperature 25. of the gas during the process will be: [**JEE-Mains-2016**]



$$(1) \frac{9P_0V_0}{nR}$$

(2)
$$\frac{9P_0V_0}{4nR}$$

(3)
$$\frac{3P_0V_0}{2nR}$$

(4)
$$\frac{9P_0V_0}{2nR}$$

KT0115

E

EH0136 The temperature of an open room of volume 30 m³ increases from 17°C to 27°C due to sunshine. The 28. atmospheric pressure in the room remains 1×10^5 Pa. If n_i and n_r are the number of molecules in the room before and after heating, then $n_f - n_i$ will be :-[**JEE-Main 2017**]

 $(1) 2.5 \times 10^{25}$

 $(2) -2.5 \times 10^{25}$

 $(3) -1.61 \times 10^{23}$

(4) 30°C ; $\alpha = 1.85 \times 10^{-3} / {^{\circ}\text{C}}$

 $(4) 1.38 \times 10^{23}$

KT0117

 C_p and C_v are specific heats at constant pressure and constant volume respectively. It is observed that $C_p^r - C_v = a$ for hydrogen gas

 $C_p - C_v = b$ for nitrogen gas

(3) 60°C ; $\alpha = 1.85 \times 10^{-4} / {^{\circ}\text{C}}$

The correct relation between a and b is:

[JEE-Main 2017]

(1) a = 14 b

(2) a = 28 b

(3) $a = \frac{1}{14}b$

(4) a = b

KT0118

30. A copper ball of mass 100 gm is at a temperature T. It is dropped in a copper calorimeter of mass 100gm, filled with 170 gm of water at room temperature. Subsequently, the temperature of the system is found to be 75°C. T is given by : (Given : room temperature = 30° C, specific heat of $copper = 0.1 cal/gm^{\circ}C$ [JEE-Main-2017]

 $(1) 1250^{\circ} C$

 $(2)825^{\circ}C$

(3) 800°C

(4) 885° C

EH0137

A man grows into a giant such that his linear dimensions increase by a factor of 9. Assuming that his 31. density remains same, the stress in the leg will change by a factor of: [JEE-Main-2017]

(1)81

(2) $\frac{1}{81}$

(3)9

 $(4) \frac{1}{0}$

EH0138

32. An external pressure P is applied on a cube at 0°C so that it is equally compressed from all sides. K is the bulk modulus of the material of the cube and α is its coefficient of linear expansion. Suppose we want to bring the cube to its original size by heating. The temperature should be raised by:

[JEE-Main-2017]

 $(1) \frac{3\alpha}{PK}$

(2) 3PKa

 $(3) \frac{P}{3\alpha K}$

 $(4) \frac{P}{\alpha K}$

EH0139

- **IEE-Physics**
- 33. Two moles of an ideal monoatomic gas occupies a volume V at 27°C. The gas expands adiabatically to a volume 2V. Calculate (a) the final temperature of the gas and (b) change in its internal energy.

[JEE-Main 2018]

(1) (a) 195 K (b) -2.7 kJ

(2) (a) 189 K (b) -2.7 kJ

(3) (a) 195 K (b) 2.7 kJ

(4) (a) 189 K (b) 2.7 kJ

KT0119

34. A solid sphere of radius r made of a soft material of bulk modulus K is surrounded by a liquid in a cylindrical container. A massless piston of area a floats on the surface of the liquid, covering entire cross section of cylindrical container. When a mass m is placed on the surface of the piston to compress

the liquid, the fractional decrement in the radius of the sphere, $\left(\frac{dr}{r}\right)$, is: [JEE-Main-2018]

- (1) $\frac{\text{Ka}}{3\text{mg}}$
- $(2) \frac{\text{mg}}{3\text{Ka}}$
- $(3) \frac{mg}{Ka}$
- $(4) \frac{Ka}{mg}$

EH0140

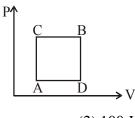
35. A 15 g mass of nitrogen gas is enclosed in a vessel at a temperature 27°C. Amount of heat transferred to the gas, so that rms velocity of molecules is doubled, is about : [Take R = 8.3 J/K mole]

[JEE-Main-2019_Jan]

- (1) 10 kJ
- (2) 0.9 kJ
- (3) 6 kJ
- (4) 14 kJ

KT0148

A gas can be taken from A to B via two different processes ACB and ADB. When path ACB is used **36.** 60 J of heat flows into the system and 30 J of work is done by the system. If path ADB is used work done by the system is 10 J. The heat Flow into the system in path ADB is: [JEE-Main-2019_Jan]



(1) 80 J

(2) 20 J

 $(3)\ 100\ J$

(4) 40 J

KT0149

- **37.** A mixture of 2 moles of helium gas (atomic mass = 4 u), and 1 mole of argon gas (atomic mass
 - = 40 u) is kept at 300 K in a container. The ratio of their rms speeds $\left| \frac{V_{rms}(helium)}{V_{rms}((arg on))} \right|$, is close to:

[JEE-Main-2019_Jan]

- (1)2.24
- (2)0.45
- (3)0.32
- (4)3.16

KT0150

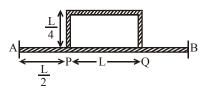
- 38. A rod, of length L at room temperature and uniform area of cross section A, is made of a metal having coefficient of linear expansion α /°C. It is observed that an external compressive force F, is applied on each of its ends, prevents any change in the length of the rod, when its temperature rises by ΔT K. Young's modulus, Y, for this metal is: [JEE-Main-2019_Jan]
- $(2) \frac{F}{A\alpha(\Delta T 273)} \qquad (3) \frac{F}{A\alpha\Delta T}$

EH0164

39. Temperature difference of 120°C is maintained between two ends of a uniform rod AB of length 2L.

Another bent rod PQ, of same cross-section as AB and length $\frac{3L}{2}$, is connected across AB (See figure). In steady state, temperature difference between P and Q will be close to:

[JEE-Main-2019_Jan]



- $(1)60^{\circ}C$
- $(2)75^{\circ}C$
- $(3) 35^{\circ}C$
- $(4) 45^{\circ}C$

EH0165

40. An unknown metal of mass 192 g heated to a temperature of 100°C was immersed into a brass calorimeter of mass 128 g containing 240 g of water a temperature of 8.4°C Calculate the specific heat of the unknown metal if water temperature stabilizes at 21.5°C (Specific heat of brass is 394 J kg⁻¹ K⁻¹)

[JEE-Main-2019_Jan]

- (1) 1232 J kg⁻¹ K⁻¹
- (2) 458 J kg⁻¹ K⁻¹
- (3) 654 J kg⁻¹ K⁻¹
- (4) 916 J kg⁻¹ K⁻¹

EH0166

41. Half mole of an ideal monoatomic gas is heated at constant pressure of 1atm from 20 °C to 90°C. Work done by gas is close to : (Gas constant R = 8.31 J/mol.K) [JEE-Main-2019 Jan]

- (1)73J
- (2) 291 J
- (3) 581 J
- (4) 146 J

KT0151

42. Two kg of a monoatomic gas is at a pressure of 4×10^4 N/m². The density of the gas is 8 kg/m³. What is the order of energy of the gas due to its thermal motion? [JEE-Main-2019_Jan]

- $(1) 10^3 J$
- $(2) 10^5 J$
- $(3) 10^6 J$
- $(4) 10^4 J$

KT0152

43. A heat source at $T = 10^3$ K is connected to another heat reservoir at $T = 10^2$ K by a copper slab which is 1 m thick. Given that the thermal conductivity of copper is 0.1 WK⁻¹ m⁻¹, the energy flux through it in the steady state is : [JEE-Main-2019_Jan]

- $(1) 90 \text{ Wm}^{-2}$
- (2) 200 Wm⁻²
- $(3) 65 \text{ Wm}^{-2}$
- (4) 120 Wm⁻²

EH0167

44. Two rods A and B of identical dimensions are at temperature 30°C. If A is heated upto 180°C and B upto T°C, then the new lengths are the same. If the ratio of the coefficients of linear expansion of A and B is 4 : 3, then the value of T is :- [JEE-Main-2019_Jan]

- (1) 270° C
- $(2) 230^{\circ}C$
- $(3) 250^{\circ}C$
- (4) 200°C

EH0168

45. When 100 g of a liquid A at 100°C is added to 50 g of a liquid B at temperature 75°C, the temperature of the mixture becomes 90°C. The temperature of the mixture, if 100 g of liquid A at 100°C is added to 50 g of liquid B at 50°C, will be :- [JEE-Main-2019_Jan]

- (1) 80°C
- $(2) 60^{\circ} C$
- $(3) 70^{\circ} C$
- (4) 85°C

EH0169

1/10.10.100.245/DTPDatchrode06/2020-21(B0B0-BA)V.Kata/UELAdvanced/Woodule Coding (V-Tog)/Leader/Rhysics/Thermal Physics/English/Dd_JM.pds

$$(1) \frac{1}{2} R\Delta T$$

$$(2) \frac{3}{2} R\Delta T$$

(2)
$$\frac{3}{2}$$
R Δ T (3) $\frac{1}{2}$ KR Δ T (4) $\frac{2K}{3}\Delta$ T

$$(4) \; \frac{2K}{3} \Delta T$$

KT0153

A metal ball of mass 0.1 kg is heated upto 500°C and dropped into a vessel of heat capacity **47.** 800 JK⁻¹ and containing 0.5 kg water. The initial temperature of water and vessel is 30°C. What is the approximate percentage increment in the temperature of the water? [Specific Heat Capacities of water and metal are, respectively, 4200 Jkg⁻¹K⁻¹ and 400 JKg⁻¹K⁻¹] [JEE-Main-2019 Jan]

(1)30%

(2)20%

(3)25%

(4) 15%

EH0170

A rigid diatomic ideal gas undergoes an adiabatic process at room temperature. The relation between 48. temperature and volume of this process is $TV^x = \text{constant}$, then x is : [JEE-Main-2019 Jan]

 $(1)\frac{5}{2}$

 $(2)\frac{2}{5}$

 $(3)\frac{2}{3}$

 $(4) \frac{3}{5}$

KT0154

49. The gas mixture constists of 3 moles of oxygen and 5 moles of argon at temperature T. Considering only translational and rotational modes, the total inernal energy of the system is:

[JEE-Main-2019_Jan]

(1) 12 RT

(2) 20 RT

(3) 15 RT

(4) 4 RT

KT0155

Ice at -20° C os added tp 50 g of water at 40°C. When the temperature of the mixture reaches 0°C, it 50. is found that 20 g of ice is still unmelted. The amount of ice added to the water was close to (Specific heat of water = $4.2 \text{ J/g/}^{\circ}\text{C}$)

Specific heat of Ice = $2.1 \text{ J/g/}^{\circ}\text{C}$

Heat of fusion of water at 0° C = 334 J/g)

[JEE-Main-2019_Jan]

(1) 50 g

(2) 40 g

(3) 60 g

 $(4)\ 100\ g$

EH0171

A vertical closed cylinder is separated into two parts by a frictionless piston of mass m and of negligible **51.** thickness. The piston is free to move along the length of the cylinder. The length of the cylinder above the piston is ℓ_1 , and that below the piston is ℓ_2 , such that $\ell_1 > \ell_2$. Each part of the cylinder contains n moles of an ideal gas at equal temperature T. If the piston is stationary, its mass, m, will be given by: (R is universal gas constant and g is the acceleration due to gravity)

[JEE-Main-2019_Jan]

$$(1) \frac{\mathsf{nRT}}{\mathsf{g}} \left[\frac{1}{\ell_2} + \frac{1}{\ell_1} \right] \qquad (2) \frac{\mathsf{nRT}}{\mathsf{g}} \left[\frac{\ell_1 - \ell_2}{\ell_1 \ell_2} \right] \qquad (3) \frac{\mathsf{RT}}{\mathsf{g}} \left[\frac{2\ell_1 + \ell_2}{\ell_1 \ell_2} \right] \qquad (4) \frac{\mathsf{RT}}{\mathsf{ng}} \left[\frac{\ell_1 - 3\ell_2}{\ell_1 \ell_2} \right]$$

$$(2) \frac{\text{nRT}}{\text{g}} \left[\frac{\ell_1 - \ell_2}{\ell_1 \ell_2} \right]$$

$$(3) \frac{RT}{g} \left[\frac{2\ell_1 + \ell_2}{\ell_1 \ell_2} \right]$$

$$(4) \frac{RT}{ng} \left[\frac{\ell_1 - 3\ell_2}{\ell_1 \ell_2} \right]$$

- 52. A cylinder of radius R is surrounded by a cylindrical shell of inner radius R and outer radius 2R. The thermal conductivity of the material of the inner cylinder is K_1 and that of the outer cylinder is K_2 . Assuming no loss of heat, the effective thermal conductivity of the system for heat flowing along the length of the cylinder is: [JEE-Main-2019_Jan]
 - $(1) K_1 + K_2$
- (2) $\frac{K_1 + K_2}{2}$ (3) $\frac{2K_1 + 3K_2}{5}$ (4) $\frac{K_1 + 3K_2}{4}$

EH0172

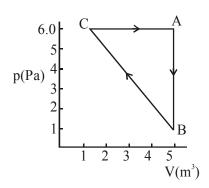
53. An ideal gas occupies a volume of $2m^3$ at a pressure of 3×10^6 Pa. The energy of the gas is:

[JEE-Main-2019_Jan]

- $(1) 3 \times 10^2$
- $(2)\ 10^8 \,\mathrm{J}$
- $(3) 6 \times 10^4 \text{ J}$
- $(4) 9 \times 10^6 J$

KT0157

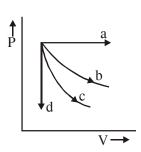
54. For the given cyclic process CAB as shown for a gas, the work done is: [JEE-Main-2019_Jan]



- (1) 1 J
- (2) 5 J
- (3) 10 J
- (4) 30 J

KT0158

55. The given diagram shows four processes i.e., isochoric, isobaric, isothermal and adiabatic. The correct [JEE-Main-2019_April] assignment of the processes, in the same order is given by :-



- (1) d a c b
- (2) a d c b
- (3) a d b c
- (4) dabc

KT0159

56. The temperature, at which the root mean square velocity of hydrogen molecules equals their escape velocity from the earth, is closest to:

[Boltzmann Constant $k_B = 1.38 \times 10^{-23} \text{ J/K}$

Avogadro Number $N_A = 6.02 \times 10^{26} / \text{kg}$

Radius of Earth: 6.4×10^6 m

Gravitational acceleration on Earth = 10ms⁻²]

[JEE-Main-2019_April]

- (1) 650 K
- $(2) 3 \times 10^5 \text{ K}$
- $(3) 10^4 \text{ K}$
- (4) 800 K

57. A boy's catapult is made of rubber cord which is 42 cm long, with 6 mm diameter of cross-section and of negligible mass. The boy keeps a stone weighing 0.02kg on it and stretches the cord by 20 cm by applying a constant force. When released, the stone flies off with a velocity of 20ms⁻¹. Neglect the change in the area of cross-section of the cord while stretched. The Young's

[JEE-Main-2019_April]

 $(1) 10^4 \, \text{Nm}^{-2}$

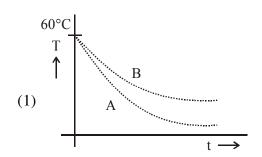
modulus of rubber is closest to:

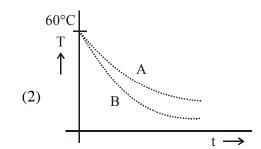
- $(2) 10^8 \, \text{Nm}^{-2}$
- $(3)\ 10^6\ Nm^{-2}$
- $(4) 10^3 \,\mathrm{Nm}^{-2}$

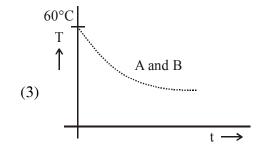
EH0173

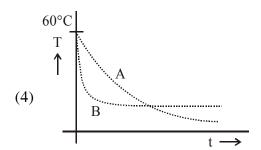
58. Two identical breakers A and B contain equal volumes of two different liquids at 60°C each and left to cool down. Liquid in A has density of 8×10^2 kg/m³ and specific heat of 2000 J kg⁻¹ K⁻¹ while liquid in B has density of 10^3 kg m⁻³ and specific heat of 4000 J kg⁻¹ K⁻¹. Which of the following best describes their temperature versus time graph schematically? (assume the emissivity of both the beakers to be the same)

[JEE-Main-2019_April]









KT0161

59. A steel wire having a radius of 2.0 mm, carrying a load of 4 kg, is hanging from a ceiling. Given that $g = 3.1 \pi \text{ ms}^{-2}$, what will be the tensile stress that would be developed in the wire?

[JEE-Main-2019_April]

- $(1) 4.8 \times 10^6 \,\mathrm{Nm}^{-2}$
- (2) $5.2 \times 10^6 \text{ Nm}^{-2}$
- $(3) 6.2 \times 10^6 \,\mathrm{Nm^{-2}}$
- $(4) 3.1 \times 10^6 \,\mathrm{Nm}^{-2}$

EH0174

- **60.** A thermally insulated vessel contains 150g of water at 0°C. Then the air from the vessel is pumped out adiabatically. A fraction of water turns into ice and the rest evaporates at 0°C itself. The mass of evaporated water will be closest to: (Latent heat of vaporization of water = 2.10×10^6 J kg⁻¹ and Latent heat of Fusion of water = 3.36×10^5 J kg⁻¹)

 [JEE-Main-2019_April]
 - (1) 130 g
- (2) 35 g
- (3) 20 g
- (4) 150 g

EH0175

\\10.10.100.245\DTROut\node06\2020-21[8080-8A]\Kota\UEE[Advanced]\Wodule Coding|V-Togl\Lacde\Iffysics\Themal Physics\Endish\04_JMp65

If 10^{22} gas molecules each of mass 10^{-26} kg collide with a surface (perpendicular to it) elastically per 61. second over an area 1 m² with a speed 10⁴ m/s, the pressure exerted by the gas molecules will be of [JEE-Main-2019_April] the order of:

 $(1) 10^8 \text{ N/m}^2$

 $(2) 10^4 \text{ N/m}^2$

 $(3) 10^3 \text{ N/m}^2$

 $(4)\ 10^{16}\ \text{N/m}^2$

KT0162

62. A massless spring (k = 800 N/m), attached with a mass (500 g) is completely immersed in 1 kg of water. The spring is stretched by 2 cm and released so that it starts vibrating. What would be the order of magnitude of the change in the temperature of water when the vibrations stop completely? (Assume that the water container and spring receive negligible heat and specific heat of mass = 400 J/kg K, specific heat of water = 4184 J/kg K) [JEE-Main-2019_April]

 $(1) 10^{-3} K$

 $(2)\ 10^{-4}\ K$

 $(3)\ 10^{-1}\ K$

 $(4) 10^{-5} \text{K}$

EH0176

- The specific heats, C_p and C_v of a gas of diatomic molecules, A, are given (in units of J mol⁻¹ K⁻¹) by **63.** 29 and 22, respectively. Another gas of diatomic molecules, B, has the corresponding values 30 and 21. If they are treated as ideal gases, then:-[JEE-Main-2019_April]
 - (1) A has one vibrational mode and B has two
 - (2) Both A and B have a vibrational mode each
 - (3) A is rigid but B has a vibrational mode
 - (4) A has a vibrational mode but B has none

KT0163

64. Two materials having coefficients of thermal conductivity '3K' and 'K' and thickness 'd' and '3d', respectively, are joined to form a slab as shown in the figure. The temperatures of the outer surfaces are ' θ_2 ' and ' θ_1 ' respectively, ($\theta_2 > \theta_1$). The temperature at the interface is :- [JEE-Main-2019_April]

$$\theta_{2}$$
 $\frac{d}{3K}$ $\frac{3d}{K}$ θ_{1}

 $(1) \ \frac{\theta_2 + \theta_1}{2}$

 $(2) \frac{\theta_1}{10} + \frac{9\theta_2}{10}$

 $(3) \frac{\theta_1}{3} + \frac{2\theta_2}{3}$

 $(4) \frac{\theta_1}{6} + \frac{5\theta_2}{6}$

EH0177

65. An HCl molecule has rotational, translational and vibrational motions. If the rms velocity of HCl molecules in its gaseous phase is \overline{v} , m is its mass and k_B is Boltzmann constant, then its temperature will be: [JEE-Main-2019_April]

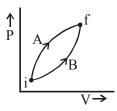
 $(1) \frac{m\overline{v}^2}{6k_B}$

 $(3) \frac{m\overline{v}^2}{3k_{\rm p}}$

 $(4) \frac{m\overline{v}^2}{7k_p}$

Following figure shows two processes A and B for a gas. If ΔQ_A and ΔQ_B are the amount of heat absorbed by the system in two cases, and ΔU_A and ΔU_B are changes in internal energies, respectively, then:

[JEE-Main-2019_April]



(1) $\Delta Q_A = \Delta Q_B$; $\Delta U_A = \Delta U_B$

(2) $\Delta Q_A > \Delta Q_B$; $\Delta U_A = \Delta U_B$

(3) $\Delta Q_A > \Delta Q_B$; $\Delta U_A > \Delta U_B$

(4) $\Delta Q_A < \Delta Q_B$; $\Delta U_A < \Delta U_B$

KT0165

- 67. For a given gas at 1 atm pressure, rms speed of the molecule is 200 m/s at 127°C. At 2 atm pressure and at 227°C, the rms speed of the molecules will be : [JEE-Main-2019_April]
 - (1) 80 m/s
- (2) $100\sqrt{5}$ m/s
- (3) $80\sqrt{5}$ m/s
- (4) 100 m/s

KT0166

- **68.** The elastic limit of brass is 379 MPa. What should be the minimum diameter of a brass rod if it is to support a 400 N load without exceeding its elastic limit? [JEE-Main-2019_April]
 - (1) 1.16 mm
- (2) 0.90 mm
- (3) 1.36 mm
- (4) 1.00 mm

EH0178

- 69. When heat Q is supplied to a diatomic gas of rigid molecules, at constant volume its temperature increases by ΔT . The heat required to produce the same change in temperature, at a constant pressure is:

 [JEE-Main-2019_April]
 - (1) $\frac{7}{5}$ Q
- $(2) \frac{3}{2} Q$
- $(3) \frac{5}{3} Q$
- $(4) \frac{2}{3}Q$

KT0167

70. In an experiment, bras and steel wires of length 1m each with areas of cross section 1 mm² are used. teh wires are connected in series and one end of the combined wire is connected to a rigid support and other end is subjected to elongation. The stress required to produce a net elongation of 0.2 mm is:

(Given, the Young's Modulus for steel and brass are respectively, 120×10^9 N/m² and 60×10^9 N/m²) [JEE-Main-2019_April]

- (1) $0.2 \times 10^6 \text{ N/m}^2$
- $(2) 4.0 \times 10^6 \text{ N/m}^2$
- (3) $1.8 \times 10^6 \text{ N/m}^2$
- $(4) 1.2 \times 10^6 \text{ N/m}^2$

EH0179

71. One mole of an ideal gas passes through a process where pressure and volume obey the relation

 $P = P_o \left[1 - \frac{1}{2} \left(\frac{V_o}{V} \right)^2 \right]$. Here P_o and V_o are constants. Calculate the change in the temperature of the gas

if its volume changes from V₀ to 2V₀.

[JEE-Main-2019_April]

- (1) $\frac{1}{2} \frac{P_{o}V_{o}}{R}$
- $(2) \frac{3}{4} \frac{P_o V_o}{R}$
- $(3) \frac{5}{4} \frac{P_o V_o}{R}$
- $(4) \frac{1}{4} \frac{P_o V_o}{R}$

72.

KT0169

KT0170

EH0180

KT0171

EH0181

[JEE-Main-2019_April]

raise the temperature of the gas by 20° C is : [Given that R = 8.31 J mol⁻¹ K⁻¹]

A cylinder with fixed capacity of 67.2 lit contains helium gas at STP. The amount of heat needed to

(1) $F/(3\pi r^2 YT)$ (2) $3F/(\pi r^2 YT)$ (3) $6F/(\pi r^2 YT)$ (4) $9F/(\pi r^2 YT)$ When M_1 gram of ice at -10° C (specific heat = 0.5 cal g^{-1} °C⁻¹) is added to M_2 gram of water at 50°C, 77. finally no ice is left and the water is at 0°C. The value of latent heat of ice, in cal g⁻¹ is: [JEE-Main-2019_April] $(1) \frac{5M_1}{M_2} - 50$ (2) $\frac{50M_2}{M_1}$ (3) $\frac{50M_2}{M_1} - 5$ (4) $\frac{5M_2}{M_1} - 5$

EH0182

Two moles of helium gas is mixed with three moles of hydrogen molecules (taken to be rigid). What is **78.** the molar specific heat of mixture at constant volume ? (R = 8.3 J/mol K) [JEE-Main-2019_April]

A uniform cylindrical rod of length L and radius r, is made from a material whose Young's modulus of Elasticity equals Y. When this rod is heated by temperature T and simultaneously subjected to a net longitudinal compressional force F, its length remains unchanged. The coefficient of volume expansion,

(1) 21.6 J/mol K

(2) 19.7 J/mol K

of the material of the rod, is (nearly) equals to:

(3) 17.4 J/mol K

(4) 15.7 J/mol K

KT0172

\\10.10.10.00.245\DTRData\nods06\2020-21[8080-8A]\Kata\UEE[Advanced]\Wodule Coding IV-Togl\Leade\\Rysics\Themal Physics\English\04_JMp65

76.

79. At 40°C, a brass wire of 1 mm radius is hung from the ceiling. A small mass, M is hung from the free end of the wire. When the wire is cooled down from 40°C to 20°C it regains its original length of 0.2m. The value of M is close to:

(Coefficient of linear expansion and Young's modulus of brass are 10^{-5} /°C and 10^{11} N/m², respectively; $g = 10 \text{ ms}^{-2}$)

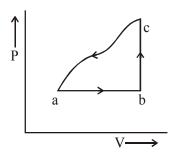
[JEE-Main-2019_April]

- (1) 1.5 kg
- (2) 9 kg
- (3) 0.9 kg
- (4) 0.5 kg

EH0183

80. A sample of an ideal gas is taken through the cyclic process abca as shown in the figure. The change in the internal energy of the gas along the path ca is –180J. The gas absorbs 250 J of heat along the path ab and 60 J along the path bc. The work done by the gas along the path abc is :

[JEE-Main-2019_April]



- (1) 100 J
- (2) 120 J
- (3) 140 J
- (4) 130 J

ANSWER KEY

01_ELASTICITY, CALORIMETRY & THERMAL EXPANSION EXERCISE (S)

2. Ans.
$$\frac{9}{16}$$

5. Ans. (a)
$$\theta = \frac{\pi}{2}$$
 (b) $\theta = \pi/4$.

6. Ans. (i) 50 N, (ii)
$$0.045 \text{ J}$$
, $1.8 \times 10^{-3} \text{ m}$ (iii) $8.4 \times 10^{-4} \text{ m}$, (iv) $x = 0.12 \text{ m}$

15. Ans.
$$5\alpha/3$$

EXERCISE (O)

02 HEAT TRANSFER

EXERCISE (S)

4. Ans.
$$(4/3)\omega$$

7. Ans. 1000 J (C°)⁻¹ 8. Ans.
$$\left(\frac{6}{\pi}\right)^{1/3}$$

8. Ans.
$$\left(\frac{6}{\pi}\right)^{1/2}$$

EXERCISE (O)

03_KTG & THERMODYNAMICS

EXERCISE (S)

- **1. Ans.** $1.25 \times 10^4 \text{ N/m}^2$
- 2. Ans. 327 °C
- 3. Ans. 40
- **4. Ans.** (a) 4/3 m, (b) $T_3 = 400 \left(\frac{4}{3}\right)^{0.4} \text{ K}$
- **5. Ans.** 3600 R
- **6. Ans.** $\Delta T = \frac{m v_0^2}{3 R}$

- **7. Ans.** 12600 J
- 8. Ans. 5R
- 9. Ans. 2.64
- **10. Ans.** 1.5

- **11. Ans.** 450 J
- **12. Ans.** 16.9 J
- 13. Ans. R/2
- **14. Ans.** (a) 0.5 atm (b) zero (c) zero (d) no

EXERCISE (O)

- 1. Ans. (A) 2. Ans. (A)
- 3. Ans. (B)
- 4. Ans. (D)
- 5. Ans. (C)
- 6. Ans. (A)

- 7. Ans. (C)
- 8. Ans. (B)
- 9. Ans. (C)
- 10. Ans. (C)
- 11. Ans. (C)
- 12. Ans. (A)

- 13. Ans. (D)
- 14. Ans. (A)
- 15. Ans. (C)
- 16. Ans. (D)
- 17. Ans. (B)
- 18. Ans. (D)

- **19.** Ans. (C)
- **20.** Ans. (C)
- 21. Ans. (A)
- 22. Ans. (C)
- 23. Ans. (D)
- 24. Ans. (B) 30. Ans. (A)

- 25. Ans. (B) 31. Ans. (A)
- 26. Ans. (C) 32. Ans. (A)
- 27. Ans. (B) 33. Ans. (D)
- 28. Ans. (D) 34. Ans. (B)
- 29. Ans. (A) 35. Ans. (B)
- **36.** Ans. (C)

- 37. Ans. (D)
- 38. Ans. (A,B,C) 39. Ans. (B,C)
- **40.** Ans. (B,C)
- 41. Ans. (D)
- **42.** Ans. (D)

43. Ans. (A)-P; (B)-Q; (C)-Q

EXERCISE (J-M)

- 1. Ans. (2)
- 2. Ans. (1)
- 3. Ans. (1)
- 4. Ans. (3)
- **5.** Ans. (1)
- 6. Ans. (4)

- 7. Ans. (4)
- 8. Ans. (2)
- 9. Ans. (3)
- 10. Ans. (4)
- 11. Ans. (1)
- 12. Ans. (4)

- 13. Ans. (2)
- **14.** Ans. (2)
- 15. Ans. (1)
- 16. Ans. (2)
- 17. Ans. (3)
- 18. Ans. (3)

- 19. Ans. (2)
- **20.** Ans. (1)
- **21.** Ans. (3)
- 22. Ans. (1)
- 23. Ans. (1)
- 24. Ans. (3)

- 25. Ans. (2)
- **26.** Ans. (3)
- 27. Ans. (2)
- 28. Ans. (2)
- 29. Ans. (1)
- 30. Ans. (4)

- 31. Ans. (3)
- **32.** Ans. (3)
- 33. Ans. (2)
- 34. Ans. (2)
- 35. Ans. (1)
- **36.** Ans. (4)

- 37. Ans. (4)
- **38.** Ans. (3)
- **39.** Ans. (4)
- **40.** Ans. (4)
- **41.** Ans. (2)
- 42. Ans. (4)

- 43. Ans. (1)
- 44. Ans. (2)
- 45. Ans. (1)
- 46. Ans. (1) 52. Ans. (4)
- 47. Ans. (2)
- 48. Ans. (2) 54. Ans. (3)

- 49. Ans. (3) 55. Ans. (4)
- 50. Ans. (2) 56. Ans. (3)
- 51. Ans. (2) 57. Ans. (3)
- 58. Ans. (1)
- 53. Ans. (4) 59. Ans. (4)
- **60.** Ans. (3)

66. Ans. (2)

78. Ans. (3)

61. Ans. (3)

67. Ans. (2)

62. Ans. (4)

68. Ans. (1)

63. Ans. (4) 69. Ans. (1)

75. Ans. (1)

64. Ans. (2) 70. Ans. (2)

76. Ans. (2)

65. Ans. (3) 71. Ans. (3)

77. Ans. (3)

72. Ans. (1)

- 73. Ans. (3) 79. Ans. (2)
- 74. Ans. (2) 80. Ans. (4)