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XI -PHYSICS **TENTATIVE ANSWER KEY** **MARKS : 70**

Q.N	PART – I		MARKS
1.	(d) $ML^{-1}T^{-1}$	(b) 1	1
2.	(a) 2s	(d) 20.0	1
3.	(b) remains same	(a) A straight line	1
4.	(a) A straight line	(a) 10Hz	1
5.	(a) momentum	(d) Less than potential energy	1
6.	(b) 4.30	(d) Only in rotating frames	1
7.	(a) 10Hz	(a) 2s	1
8.	(a) 12s	(b) 2.5vHz	1
9.	(b) 2.5vHz	(a) 12s	1
10.	(a) 10J	(b) remains same	1
11.	(c) $\frac{L}{\sqrt{2}}$	(a) 10J	1
12.	(d) Only in rotating frames	(c) $\frac{L}{\sqrt{2}}$	1
13.	(d) Less than potential energy	(a) momentum	1
14.	(b) 1	(d) $ML^{-1}T^{-1}$	1
15.	(d) 20.0	(b) 4.30	1

PART – II

Q.N	Answer	Example	MARKS
16.	i) All non-zero digits are significant	1342 has **four** significant figures	2x1=2
	ii) All zeros between two non zero digits are significant	2008 has **four** significant figures	
	iii) All zeros to the right of a non-zero digit but to the left of a decimal point are significant.	30700. has **five** significant figures	
	iv) a) The number without a decimal point, the terminal or trailing zero(s) are not significant.	a) 30700 has **three** significant figures	
	b) All zeros are significant if they come from a measurement	b) 30700 m has **five** significant figures	
	v) If the number is less than 1, the zero (s) on the right of the decimal point but to left of the first non zero digit are not significant.	0.00345 has **three**	

	vi) All zeros to the right of a decimal point and figures and to the right of non-zero digit are significant. — significant figures; 40.00 has **four** significant figures; 0.030400 has **five** significant figures vii) The number of significant figures does not depend on the system of units used — 1.53 cm, 0.0153 m, 0.0000153 km, all have **three** significant figures **(Any 2 points only)**	
17.	It is property which can be described only by magnitude. Eg; Distance, mass, temperature.	1 1
18.	The coefficient of static friction between the tyre and the surface of the road determines what maximum speed, the car can have for safe turn. $$\mu_s < \frac{v^2}{rg}(skid)$$ If the static friction is not able to provide enough centripetal force to turn, the vehicle will start to skid	2
19.	**S.No — Conservative forces — Non-conservative forces** 1. Work done is independent of the path — Work done depends upon the path 2. Work done in a round trip is zero — Work done in a round trip is not zero 3. Total energy remains constant — Energy is dissipated as heat energy 4. Work done is completely recoverable — Work done is not completely recoverable. 5. Force is the negative gradient of potential energy — No such relation exists. • Examples for conservative forces are elastic spring force, electrostatic force, magnetic force, gravitational force, etc. • Examples of non conservative forces are forces due to air resistance, viscous. **(Any 2 points only)**	2x1=2
20.	• The torque is zero when $\vec{r}$ and $\vec{F}$are parallel or ant parallel. **(or)** • If parallel, then $\theta = 0^0$and $\sin 0^0 = 0$. if anti parallel, then $\theta = 180^0$, $\sin 180^0 = 0$. Hence, $\tau = 0$. • The torque is zero if the force acts at the reference point . i.e.as $\vec{r} = 0. \tau = 0$.	1 1
21.	Newton's law of gravitation states that a particle of mass M_1 attracts any other particle of mass M_2 in the universe with an attractive force. The strength of this force of attraction was found to be directly proportional to the product of their masses and is inversely proportional to the square of the distance between them. $$\vec{F} = -\frac{GM_1M_2}{r^2}\hat{r}$$ **(only formula award 1 mark)**	2
22.	It is defined as the ratio of relative contraction (lateral strain) to relative expansion (longitudinal strain). It is denoted by the symbol μ. **(or)**	2

	$\text{poisson's ratio}, \mu = \frac{\text{lateral strain}}{\text{longitudinal strain}}$	
23.	The zeroth law of thermodynamics states that if two systems, *A* and *B*, are in thermal equilibrium with a third system, *C*, then *A* and *B* are in thermal equilibrium with each other.	2
24.	$KE = \frac{p^2}{2m}$ $KE_1 = \frac{(30)^2}{2 \times 3} = \frac{900}{6}$ $KE_1 = 150J$ $KE_2 = \frac{(30)^2}{2 \times 6} = \frac{900}{12}$ $KE_2 = 75J$ $KE_1 \neq KE_2$	½ ½ ½ ½
	PART – III	
25.	**Gross Error** The error caused due to the shear carelessness of an observer is called gross error. For example, (i) Reading an instrument without setting it properly. (ii) Taking observations in a wrong manner without bothering about the sources of errors and the precautions. (iii) Recording wrong observations. (iv) Using wrong values of the observations in calculations. These errors can be minimized only when an observer is careful and mentally alert. **(Any 2 points only)**	1 2
26.	**Properties** (i) The product quantity $\vec{A} \cdot \vec{B}$ is always a scalar. It is positive if the angle between the vectors is acute (i.e., < 90°) and negative if the angle between them is obtuse (i.e. 90°<θ< 180°). (ii) The scalar product is commutative, i.e. $\vec{A}.\vec{B} = \vec{B}.\vec{A}$ (iii) The vectors obey distributive law i.e. $\vec{A}.(\vec{B}+\vec{C}) = \vec{A}.\vec{B} + \vec{A}.\vec{C}$ (iv) The angle between the vectors $\theta = \cos^{-1}\left[\frac{\vec{A}\cdot\vec{B}}{AB}\right]$ (v) The scalar product of two vectors will be maximum when cos θ = 1, i.e. θ = 0°, i.e., when the vectors are parallel; $(\vec{A}\cdot\vec{B})_{max} = AB$ (vi) The scalar product of two vectors will be minimum, when cos θ = –1, i.e. θ = 180° $(\vec{A}\cdot\vec{B})_{min} = -AB$ when the vectors are anti-parallel. (vii) If two vectors $\vec{A}$ and $\vec{B}$ are perpendicular to each other then their scalar product $\vec{A}\cdot\vec{B} = 0$, because cos 90°= 0. Then the vectors $\vec{A}$ and $\vec{B}$ are said to be mutually orthogonal.	3x1=3

(viii) The scalar product of a vector with itself is termed as self–dot product and is given by

$$\left(\vec{A}\right)^2 = \vec{A}\cdot\vec{A} = AA\cos\theta = A^2$$

Here angle θ = 0°

The magnitude or norm of the vector

$$\vec{A} \text{ is } |\vec{A}| = A = \sqrt{\vec{A}\cdot\vec{A}}$$

(ix) In case of a unit vector $\hat{n}$

(x) In the case of orthogonal unit vectors $\hat{\imath}$, $\hat{\jmath}$ and $\hat{k}$,

$$\hat{i}.\hat{j} = \hat{j}.\hat{k} = \hat{k}.\hat{i} = 1\cdot 1\cos 90^\circ = 0$$

(xi) In terms of components the scalar product of $\vec{A}$ and $\vec{B}$ can be written as

$$\vec{A}\cdot\vec{B} = (A_x\hat{i} + A_y\hat{j} + A_z\hat{k})\cdot\left(B_x\hat{i} + B_y\hat{j} + B_z\hat{k}\right)$$

$= A_xB_x + A_yB_y + A_zB_z$, with all other terms zero.

The magnitude of vector $|\vec{A}|$ is given by

$$|\vec{A}| = A = \sqrt{A_x^2 + A_y^2 + A_z^2}$$

(Any 3 points only)

27.

Centripetal force	Centrifugal force
• It acts towards the axis of rotation or center of the circle in circular motion $\left\|F_{cp}\right\| = m\omega^2 r = \frac{mv^2}{r}$	• It acts outwards from the axis of rotation or radially outwards from the center of the circular motion $\left\|F_{cf}\right\| = m\omega^2 r = \frac{mv^2}{r}$
• It is a real force which is exerted on the body by the external agencies like gravitational force, tension in the string, normal force etc.	• It is a pseudo force or fictitious force which cannot arise from gravitational force, tension force, normal force etc.
• Acts in both inertial and non-inertial Frames	• Acts only in rotating frames (non-inertial frame)
• Real force and has real effects	• Pseudo force but has real effects
• Origin of centripetal force is interaction between two objects.	• Origin of centrifugal force is inertia. It does not arise from interaction.
• In inertial frames centripetal force has to be included when free body diagrams are drawn.	• In an inertial frame the object's inertial motion appears as centrifugal force in the rotating frame. In inertial frames there is no centrifugal force. In rotating frames, both centripetal and centrifugal force have to be included when free body diagrams are drawn.

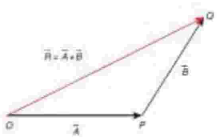
(Any 3 points only)

3x1=3

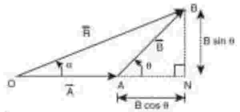
28. (i) The energy possessed by the body due to gravitational force gives rise to gravitational potential energy. U = mgh — 1

(ii) The energy due to spring force and other similar forces give rise to elastic potential energy. $U = \frac{1}{2}kx^2$ — 1

	(iii) The energy due to electrostatic force on charges gives rise to electrostatic potential energy. $U = \frac{q_1 q_2}{4\pi\varepsilon_0 r}$	1
29.	Satellites that appear to be stationary when seen from the earth are called geostationary satellites. They orbit at a height of 36,000 km. Its time period is 24 hrs.	2 ½ ½
30	**Practical applications of capillarity** • Due to capillary action, oil rises in the cotton within an earthen lamp. Likewise, sap rises from the roots of a plant to its leaves and branches. • Absorption of ink by a blotting paper. • Capillary action is also essential for the tear fluid from the eye to drain constantly. • Cotton dresses are preferred in summer because cotton dresses have fine pores which act as capillaries for sweat. **(Any 3 points only)**	3
31.	**Laws of simple pendulum** The time period of a simple pendulum **a. Depends on the following laws** **(i) Law of length** For a given value of acceleration due to gravity, the time period of a simple pendulum is directly proportional to the square root of length of the pendulum. $T \propto \sqrt{l}$ **(ii) Law of acceleration** For a fixed length, the time period of a simple pendulum is inversely proportional to square root of acceleration due to gravity. $T \propto \frac{1}{\sqrt{g}}$ The time period of oscillation is independent of mass of the simple pendulum. For a pendulum with small angle approximation (angular displacement is very small), the time period is independent of amplitude of the oscillation.	1 1 1
32.	1. All the molecules of a gas are identical, elastic spheres. 2. The molecules of different gases are different. 3. The number of molecules in a gas is very large and the average separation between them is larger than size of the gas molecules. 4. The molecules of a gas are in a state of continuous random motion. 5. The molecules collide with one another and also with the walls of the container. 6. These collisions are perfectly elastic so that there is no loss of kinetic energy during collisions. 7. Between two successive collisions, a molecule moves with uniform velocity. 8. The molecules do not exert any force of attraction or repulsion on each other except during collision. The molecules do not possess any potential energy and the energy is wholly kinetic. 9. The collisions are instantaneous. The time spent by a molecule in each collision is very small compared to the time elapsed between two consecutive collisions. 10. These molecules obey Newton's laws of motion even though they move	3x1=3

	randomly. **(Any 3 points)**	
33.	$\eta = 1 - \frac{Q_L}{Q_H}$ $\eta = 1 - \frac{200}{600}$ $\eta = 0.666\ (or) 66.7\%$	1 1 1
	PART – IV	
34. a)	$T \propto m^a l^b g^c$ $T = k.\quad m^a l^b g^c$ k dimensionless constant $[T^1] = [M^a][L^b][LT^{-2}]^c$ $[M^0L^0T^1] = [M^a L^{b+c} T^{-2c}]$ $a = 0,\ b + c = 0,\ -2c = 1$ $a = 0,\ b = 1/2$, and $c = -1/2$ $T = k.\ m_0\ \ell_{1/2}\ g_{-1/2}$ $T = k\left(\frac{\ell}{g}\right)^{1/2} = k\sqrt{\ell/g}$ $k = 2\pi$, $T = 2\pi\sqrt{\ell/g}$	5
34. (OR) b)	**LAW** • Represent the vectors $\vec{A}$ and $\vec{B}$ by the two adjacent sides of a triangle taken in the same order. Then the resultant is given by the third side of the triangle as shown in Figure  • To explain further, the head of the first vector $\vec{A}$ is connected to the tail of the second vector $\vec{B}$. Let θ be the angle between $\vec{A}$ and $\vec{B}$. Then $\vec{R}$ is the resultant vector connecting the tail of the first vector $\vec{A}$ to the head of the second vector $\vec{B}$. The magnitude of $\vec{R}$ (resultant) is given geometrically by the length of $\vec{R}$ (OQ) and the direction of the resultant vector is the angle between $\vec{R}$ and $\vec{A}$. Thus we write $\vec{R} = \vec{A} + \vec{B}$ $\overrightarrow{OQ} = \overrightarrow{OP} + \overrightarrow{PQ}$ **(1) Magnitude of resultant vector** • consider the triangle ABN, which is obtained by extending the side OA	5

to ON. ABN is a right angled triangle.



$$\cos\theta = \frac{AN}{B} \therefore AN = B\cos\theta \; and$$

$$\sin\theta = \frac{BN}{B} \quad \therefore BN = B\sin\theta$$

For ΔOBN, we have $OB^2 = ON^2 + BN^2$

$$\Rightarrow R^2 = (A + B\cos\theta)^2 + (B \sin\theta)^2$$

$$\Rightarrow R^2 = A^2 + B^2\cos^2\theta + 2AB\cos\theta + B^2\sin^2\theta$$

$$\Rightarrow R^2 = A^2 + B^2\left(\cos^2\theta + \sin^2\theta\right) + 2AB\cos\theta$$

$$\Rightarrow R = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

which is the magnitude of the resultant of $\vec{A}$ and $\vec{B}$

(2) Direction of resultant vectors:

- If θ is the angle between $\vec{A}$ and $\vec{B}$, then

$$\left|\vec{A} + \vec{B}\right| = \sqrt{A^2 + B^2 + 2AB\cos\theta}$$

If $\vec{R}$ makes an angle α with $\vec{A}$, then in ΔOBN,

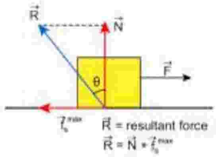
$$\tan\alpha = \frac{BN}{ON} = \frac{BN}{OA + AN}$$

$$\tan\alpha = \frac{B\sin\theta}{A + B\cos\theta}$$

$$\Rightarrow \alpha = \tan^{-1}\left(\frac{B\sin\theta}{A + B\cos\theta}\right)$$

35. a) **Angle Of Friction** (5)

- The angle of friction is defined as the angle between the normal force (N) and the resultant force (R) of normal force and maximum friction force (f_s^{max})



- the resultant force is

$$R = \sqrt{\left(f_s^{max}\right)^2 + N^2}$$

$$\tan\theta = \frac{f_s^{max}}{N} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

- But from the frictional relation, the object begins to slide when $f_s^{max} = \mu_s N$

or when $\frac{f_s^{max}}{N} = \mu_s$ …………… (2)

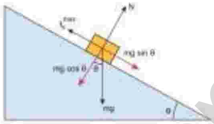
- From equations (1) and (2) the coefficient of static friction is

$\mu_s = tan\theta$ …………….. (3)

- ***The coeffi cient of static friction is equal to tangent of the angle of friction***

Angle of Repose

- Consider an inclined plane on which an object is placed, as shown in Figure. Let the angle which this plane makes with the horizontal be θ. For small angles of θ , the object may not slide down.
- As θ is increased, for a particular value of θ, the object begins to slide down. Th is value is called angle of repose.
- Hence, the angle of repose is the angle of inclined plane with the horizontal such that an object placed on it begins to slide.



- Let us consider the various forces in action here. Th e gravitational force mg is resolved into components parallel (*mg* sin θ) and perpendicular (*mg* cos θ) to the inclined plane.
- The component of force parallel to the inclined plane (mg sin θ) tries to move the object down. The component of force perpendicular to the inclined plane (mg cos θ) is balanced by the Normal force (N).

$N = mg\cos\theta$ ……………… (1)

- When the object just begins to move, the static friction attains its maximum value

$$f_s = f_s^{max} = \mu_s N = \mu_s mg\cos\theta$$

- Th is friction also satisfies the relation

$$f_s^{max} = \mu_s mg\cos\theta$$

- Equating the right hand side of equations (1) and (2), we get

$$\mu_s = sin\theta / cos\theta$$

- From the definition of angle of friction, we also know that

$$\tan\theta = \mu_s$$

in which θ is the angle of friction.

- *Thus the angle of repose is the same as angle of friction.*
- But the difference is that the angle of repose refers to inclined surfaces and the angle of friction is applicable to any type of surface.

35. (OR) b) — 5

- The work done by a force $\vec{F}$ for a displacement $\overrightarrow{dr}$ is

$W = \int \vec{F} \cdot d\vec{r}$ **-------(1)**

- Left hand side of the equation (1) can be written as

$$W = \int dW = \int \frac{dW}{dt} dt$$ **-------(2)**

(multiplied and divided by dt)

- Since, velocity is

$$\vec{v} = \frac{d\vec{r}}{dt}; \; d\vec{r} = \vec{v}\, dt$$

- Right hand side of the equation (1) can be written as

$$\int \vec{F} \cdot d\vec{r} = \int \left(\vec{F} \cdot \frac{d\vec{r}}{dt} \right) dt = \int \left(\vec{F} \cdot \vec{v} \right) dt \quad \left[\vec{v} = \frac{d\vec{r}}{dt} \right]$$ **-------(3)**

- Substituting equation (2) and equation (3) in equation (1), we get

$$\int \frac{dW}{dt} dt = \int \left(\vec{F} \cdot \vec{v} \right) dt$$

$$\int \left(\frac{dW}{dt} - \vec{F} \cdot \vec{v} \right) dt = 0$$

- This relation is true for any arbitrary value of dt. This implies that the term within the bracket must be equal to zero, i.e.,

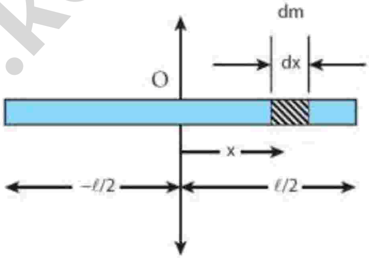
$$\frac{dW}{dt} - \vec{F} \cdot \vec{v} = 0$$

Or

$$\frac{dW}{dt} = \vec{F} \cdot \vec{v}$$ **-------(4)**

36. a)

- Let us consider a uniform rod of mass (M) and length (l) as shown in figure.
- Let us find an expression for moment of inertia of this rod about an axis that passes through the center of mass and perpendicular to the rod.



- First an origin is to be fixed for the coordinate system so that it coincides with the center of mass, which is also the geometric center of the rod. The rod is now along the x axis. We take an infinitesimally small mass (dm) at a distance (x) from the origin. The moment of inertia (dI) of this mass (dm) about the axis is,

$$dI = (dm)x^2$$

- As the mass is uniformly distributed, the mass per unit length (λ) of the rod is, $\lambda = M/l$ The (dm) mass of the infinitesimally small length as, dm $= \lambda$ dx $= \frac{M}{l}$ dx. The moment of inertia (I) of the entire rod can be found

5

by integrating dI,

$$I = \int dI = \int (dm)\, x^2 = \int \left(\frac{M}{\ell} dx \right) x^2$$

$$I = \frac{M}{\ell} \int x^2 dx$$

- As the mass is distributed on either side of the origin, the limits for integration are taken from - l / 2 to l/ 2.

$$I = \frac{M}{\ell} \int_{-\ell/2}^{\ell/2} x^2 dx = \frac{M}{\ell} \left[\frac{x^3}{3} \right]_{-\ell/2}^{\ell/2}$$

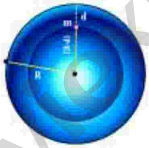
$$I = \frac{M}{\ell} \left[\frac{\ell^3}{24} - \left(-\frac{\ell^3}{24} \right) \right] = \frac{M}{\ell} \left[\frac{\ell^3}{24} + \frac{\ell^3}{24} \right]$$

$$I = \frac{M}{\ell} \left[2 \left(\frac{\ell^3}{24} \right) \right]$$

$$I = \frac{1}{12} M \ell^2$$

36 (OR) b) — 5

- Consider a particle of mass m which is in a deep mine on the Earth. (Example: coal mines in Neyveli). Assume the depth of the mine as d. To calculate g′ at a depth d, consider the following points.



- The part of the Earth which is above the radius (R_e − d) do not contribute to the acceleration. The result is proved earlier and is given as

$$g' = \frac{GM'}{(R_e - d)^2}$$

- Here M’ is the mass of the Earth of radius. Assuming the density of Earth ρ to be constant,

$$\rho = \frac{M}{V}$$

- where is the mass of the Earth and V its volume, Thus,

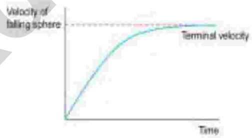
$$\rho = \frac{M'}{V'}$$

$$\frac{M'}{V'} = \frac{M}{V} \text{ and } M' = \frac{M}{V} V'$$

$$M' = \left(\frac{M}{\frac{4}{3}\pi R_e^3} \right) \left(\frac{4}{3}\pi (R_e - d)^3 \right)$$

$$M' = \frac{M}{R_e^3} (R_e - d)^3$$

$$g' = G \frac{M}{R_e^3} (R_e - d)^3 . \frac{1}{(R_e - d)^2}$$

	$$g' = GM\frac{R_e\left(1-\frac{d}{R_e}\right)}{R_e^3}$$ $$g' = GM\frac{\left(1-\frac{d}{R_e}\right)}{R_e^2}$$ $$g' = g\left(1-\frac{d}{R_e}\right)$$ • Here also g' < g. As depth increases, g' decreases. It is very interesting to know that acceleration due to gravity is maximum on the surface of the Earth but decreases when we go either upward or downward.	
37. (a)	• To understand terminal velocity, consider a small metallic sphere falling freely from rest through a large column of a viscous fluid. • The forces acting on the sphere are (i) gravitational force of the sphere acting vertically downwards, (ii) upthrust U due to buoyancy and (iii) viscous drag acting upwards (viscous force always acts in a direction opposite to the motion of the sphere). • Initially, the sphere is accelerated in the downward direction so that the upward force is less than the downward force. As the velocity of the sphere increases, the velocity of the viscous force also increases. • A stage is reached when the net downward force balances the upward force and hence the resultant force on the sphere becomes zero. It now moves down with a constant velocity. • The maximum constant velocity acquired by a body while falling freely through a viscous medium is called the terminal velocity Vt. In the Figure, a graph is drawn with velocity along y- axis and time along x-axis.  • It is evident from the graph that the sphere is accelerated initially and in course of time it becomes constant, and attains terminal velocity (V_t). **Expression for terminal velocity:** • Consider a sphere of radius *r* which falls freely through a highly viscous liquid of coefficient of viscosity η. Let the density of the material of the sphere be ρ and the density of the fluid be σ.  • Gravitational force acting on the sphere, $$F_G = mg = \frac{4}{3}\pi r^3 \rho g \text{ (downward force)}$$	5

Up thrust, $U = \frac{4}{3}\pi r^3 \sigma g$ (upward force)

viscous force $F = 6\pi\eta r v_t$

At terminal velocity v_t.

- downward force = upward force

$$F_G - U = F \Rightarrow \frac{4}{3}\pi r^3 \rho g - \frac{4}{3}\pi r^3 \sigma g = 6\pi\eta r v_t$$

$$v_t = \frac{2}{9} \times \frac{r^2(\rho - \sigma)}{\eta} g \Rightarrow v_t \propto r^2$$

- Here, it should be noted that the terminal speed of the sphere is directly proportional to the square of its radius. If σ is greater than ρ, then the term (ρ - σ) becomes negative leading to a negative terminal velocity.
- That is why air bubbles rise up through water or any fluid. This is also the reason for the clouds in the sky to move in the upward direction.

37. (b)

- Consider μ mole of an ideal gas in a container with volume V, pressure P and temperature T. When the gas is heated at constant volume the temperature increases by dT. As no work is done by the gas, the heat that flows into the system will increase only the internal energy. Let the change in internal energy be dU.
- If C_v is the molar specific heat capacity at constant volume, from equation

$$dU = \mu C_v dT$$

- Suppose the gas is heated at constant pressure so that the temperature increases by dT. If 'Q' is the heat supplied in this process and 'dV' the change in volume of the gas.

$$Q = \mu C_p dT$$

- If W is the workdone by the gas in this process, then

$$W = PdV$$

- But from the first law of thermodynamics,

$$Q = dU + W$$

- Substituting equations we get,

$$\mu C_p dT = \mu C_v dT + PdV$$

- For mole of ideal gas, the equation of state is given by

$$PV = \mu RT \Rightarrow PdV + VdP = \mu RdT$$

- Since the pressure is constant, dP = 0

$$\therefore C_p dT = C_v dT + RdT$$

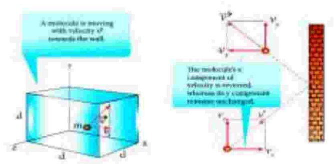
$$\therefore C_p = C_v + R \quad \text{(or)} \quad C_p - C_v = R$$

- This relation is called Meyer's relation. It implies that the molar specific heat capacity of an ideal gas at constant pressure is greater than molar specific heat capacity at constant volume.
- The relation shows that specific heat at constant pressure (s_p) is always greater that specific heat at constant volume (s_v).

Marks: 5

38. (a)

- Consider a monatomic gas of N molecules each having a mass m inside a cubical container of side *l* as shown in the Figure



- The molecules of the gas are in random motion. They collide with each other and also with the walls of the container. As the collisions are elastic in nature, there is no loss of energy, but a change in momentum occurs.
- The molecules of the gas exert pressure on the walls of the container due to collision on it. During each collision, the molecules impart certain momentum to the wall.
- Due to transfer of momentum, the walls experience a continuous force. The force experienced per unit area of the walls of the container determines the pressure exerted by the gas.
- It is essential to determine the total momentum transferred by the molecules in a short interval of time.
- A molecule of mass m moving with a velocity having components (v_x, v_y, v_z) hits the right side wall. Since we have assumed that the collision is elastic, the particle rebounds with same speed and its x - component is reversed.
- The components of velocity of the molecule after collision are ($-v_x$, v_y, v_z).
- The x-component of momentum of the molecule before collision = mv_x
- The x-component of momentum of the molecule aft er collision = $-mv_x$
- The change in momentum of the molecule in x direction = Final momentum – initial momentum = $-mv_x - mv_x = -2mv_x$
- According to law of conservation of linear momentum, the change in momentum of the wall = $2mv_x$
- The number of molecules hitting the right side wall in a small interval of time Δt is calculated as follows.
- The molecules within the distance of $v_x\Delta t$ from the right side wall and moving towards the right will hit the wall in the time interval Δt.
- The number of molecules that will hit the right side wall in a time interval Δt is equal to the product of volume ($Av_x\Delta t$) and number density of the molecules (n). Here A is area of the wall and n is number of molecules per unit volume N/V
- We have assumed that the number density is the same throughout the cube.
- Not all the n molecules will move to the right, therefore on an average only half of the n molecules move to the right and the other half moves

5

	towards left side. Th e number of molecules that hit the right side wall in a time interval Δt $$= \frac{n}{2} A v_x \Delta t$$ • In the same interval of time Δt, the total momentum transferred by the molecules $$\Delta p = \frac{n}{2} A v_x \Delta t \times 2mv_x = Av_x^2 mn\Delta t$$ • From Newton's second law, the change in momentum in a small interval of time gives rise to force. The force exerted by the molecules on the wall (in magnitude) $$F = \frac{\Delta p}{\Delta t} = nmAv_x^2$$ • Pressure, P = force divided by the area of the wall $$P = \frac{F}{A} = nmv_x^2$$ • Since all the molecules are moving completely in random manner, they do not have same speed. So we can replace the term v_x^2 by the average v_x^2 in equation $$P = nm\overline{v_x^2}$$ • Since the gas is assumed to move in random direction, it has no preferred direction of motion (the effect of gravity on the molecules is neglected). It implies that the molecule has same average speed in all the three direction. So, $$\overline{v_x^2} = \overline{v_y^2} = \overline{v_z^2}$$ • The mean square speed is written as $$\overline{v^2} = \overline{v_x^2} + \overline{v_y^2} + \overline{v_z^2} = 3\overline{v_x^2}$$ $$\overline{v_x^2} = \frac{1}{3}\overline{v^2}$$ • Using this in equation, we get $$P = \frac{1}{3}nm\overline{v^2} \text{ or } P = \frac{1}{3}\frac{N}{V}m\overline{v^2}$$ $$\text{as } \left[n = \frac{N}{V}\right]$$ • The following inference can be made from the above equation. The pressure exerted by the molecules depends on	
38. (b)	**Newton's formula for speed of sound waves in air** • Sir Isaac Newton assumed that when sound propagates in air, the formation of compression and rarefaction takes place in a very slow manner so that the process is isothermal in nature. • That is, the heat produced during compression (pressure increases, volume decreases), and heat lost during rarefaction (pressure decreases, volume increases) occur over a period of time such that the temperature of the medium remains constant. • Therefore, by treating the air molecules to form an ideal gas, the changes in	

pressure and volume obey Boyle's law, Mathematically

$$PV = \text{Constant}$$

- Differentiating equation , we get

$$PdV + VdP = 0$$

$$\text{or,} \quad P = -V\frac{dP}{dV} = B_T$$

5

where, B_T is an isothermal bulk modulus of air. Substituting, the speed of sound in air is

$$v_T = \sqrt{\frac{B_T}{\rho}} = \sqrt{\frac{P}{\rho}}$$

Since P is the pressure of air whose value at NTP (Normal Temperature and Pressure) is 76 cm of mercury, we have

$$P = (0.76 \times 13.6 \times 10^3 \times 9.8)\ N\ m^{-2}$$

$$\rho = 1.293\ kg\ m^{-3}$$

here ρ is density of air.

- Then the speed of sound in air at Normal Temperature and Pressure (NTP) is

$$v_T = \sqrt{\frac{(0.76 \times 13.6 \times 10^3 \times 9.8)}{1.293}}$$

$= 279.80\ m\ s^{-1} \approx 280\ ms^{-1}$ (theoretical value)

- But the speed of sound in air at 0 °C is experimentally observed as 332 ms^{-1} which is close upto 16 % more than theoretical value (Percentage error is

$$\frac{(332 - 280)}{332} \times 100\% = 15.6\%\ )$$

- This error is not small.

Laplace's correction

- Laplace satisfactorily corrected this discrepancy by assuming that when the sound propagates through a medium, the particles oscillate very rapidly such that the compression and rarefaction occur very fast.
- Hence the exchange of heat produced due to compression and cooling effect due to rarefaction do not take place, because, air (medium) is a bad conductor of heat. Since, temperature is no longer considered as a constant here, sound propagation is an adiabatic process.
- By adiabatic considerations, the gas obeys Poisson's law (not Boyle's law as Newton assumed), which is

$$PV^\gamma = \text{constant}$$

$$\text{where,} \quad \gamma = \frac{C_P}{C_v}$$

which is the ratio between specific heat at constant pressure and specific heat at constant volume.

Differentiating equation on both the sides, we get

$$V^\gamma\, dP + P\,(\gamma V^{\gamma-1}\, dV) = 0$$

$$\text{or,} \quad \gamma P = -V\frac{dp}{dV} = B_A$$

	where, B_A is the adiabatic bulk modulus of air. Now, substituting, the speed of sound in air is $$v_A = \sqrt{\frac{B_A}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma}\, v_T$$ Since air contains mainly, nitrogen, oxygen, hydrogen etc, (diatomic gas), we take $\gamma = 1.47$. Hence, speed of sound in air is $v_A = (\sqrt{1.47})(280 \text{ m s}^{-1}) = 331.30 \text{ m s}^{-1}$, which is very much closer to experimental data.	

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