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HIGHER SECONDARY FIRST YEAR

HALF YEARLY EXAMINATION, DEC'2024

STD: 11. **PHYSICS KEY ANSWER** **MARKS: 75.**

PART-I

CHOOSE:- **15 X 1 = 15**

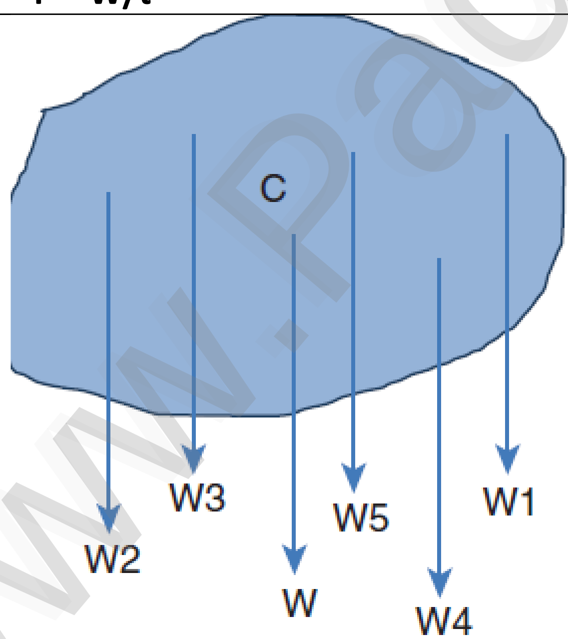
Q.NO.	OPTION CODE	ANSWER	MARKS
1.	b)	20.0	1
2	c)	momentum	1
3.	a)	Inertia of direction	1
4.	b)	Zero	1
5.	a)	Pure rotation	1
6.	d)	$L/\sqrt{2}$	1
7.	c)	Increases 4 times	1
8.	b)	Always negative	1
9.	b)	g/2	1
10.	a)	1	1
11.	d)	Stress	1
12.	d)	Infinity	1
13.	a)	Remains same	1
14.	a)	Room A	1
15.	d)	A straightline	1

PART-II

ANSWER ANY 'SIX': **6 X 2 = 12**

QN.NO. '23' COMPULSORY

16.	* The Radian (rad): *One radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.* • 1 radian = 57.27°_	2

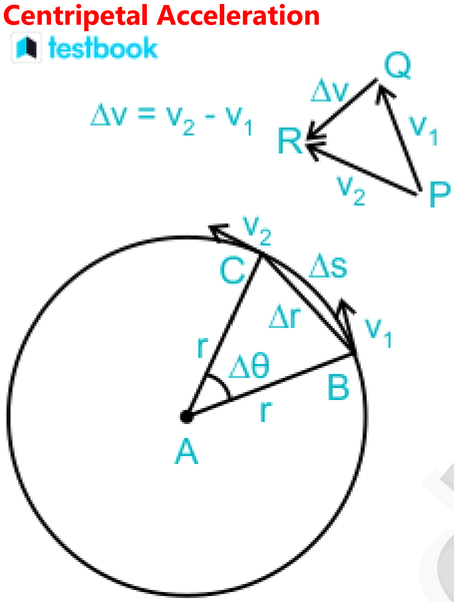
<table>
<tr><td>17.</td><td>* Scalar
It is a property which can be described only by magnitude. In physics a number of quantities can be described by scalars.
• Examples
Distance, mass, temperature, speed and energy.
• Vector
It is a quantity which is described by both magnitude and direction. Geometrically a vector is a directed line segment which is shown in Figure 2.10. In physics certain quantities can be described only by vectors.
• Examples
Force, velocity, displacement, position vector, acceleration, linear momentum and angular momentum</td><td>2 (Any 2 points with an exampl e0</td></tr>
<tr><td>18.</td><td>* There are two kinds of friction namely
1) Static friction and 2) Kinetic friction.</td><td>2</td></tr>
<tr><td>19.</td><td>* Power is a measure of how fast or slow a work is done.
* Power is defined as the rate of work done or energy delivered.
* Power (P) = work done (W)/ time taken (t)
* P = W/t</td><td>2</td></tr>
<tr><td>20.</td><td>

• The centre of gravity of a body is the point at which the entire weight of the body acts irrespective of the position</td><td>2</td></tr>
</table>

	***and orientation of the body*.**	
21.	*The Earth's spinning motion can be proved by observing star's position over a night. *Due to Earth's spinning motion, the stars in sky appear to move m circular motion about the pole star. itself-is-spinning	**2**
22.	• **Hooke's law states that for a small deformation within the elastic limit, the strain produced in a body is directly proportional to the stress that produces it.**	**2**
23.	• **The first law of thermodynamics is a statement of the law of conservation of energy.** • ***'Change in internal energy (ΔU) of the system is equal to heat supplied to the system (Q) minus the work done by the system (W) on the surroundings'.*** • **Mathematically it is written as** **$\Delta U = Q - W$**	**2**
24. [C.P.]	From a point on the ground, the top of a tree is seen to have an angle of elevation 60°. The distance between the tree and a point is 50 m. Calculate the height of the tree? ***Solution*** Angle $\theta = 60°$ The distance between the tree and a point $x = 50$ m Height of the tree (h) = ? For triangulation method $\tan\theta = \frac{h}{x}$ $h = x \tan\theta$ $= 50 \times \tan 60°$ $= 50 \times 1.732$ $h = 86.6$ m The height of the tree is 86.6 m.	**2**

PART-III

ANSWER ANY 'SIX': **6 X 3 = 18**

QN.NO. '33' COMPULSORY		
25.	**Principle of homogeneity of dimensions** • The principle of homogeneity of dimensions states that the dimensions of all the terms in a physical expression should be the same. • For example, in the physical expression $v^2 = u^2 + 2as$, the dimensions of v_2, u_2 and 2 as are the same and equal to $[L^2T^{-2}]$.	3
26.	**Centripetal Acceleration**  **Definition**: • Centripetal acceleration is the **acceleration** directed towards the center of a circular path that an object moving in a circle experiences. • Centripetal acceleration is the rate of change of tangential velocity, and **centripetal force** is the force acting that helps generate an object's centripetal acceleration in a circular motion. • The centripetal force is directed towards the centre and therefore is perpendicular to the motion of the body. • $a_c = v^2/r$ • This is the required expression for centripetal acceleration	3
27.	Question A cricketer lowers his hands to catch a ball safely. Explain why? SolutionA cricketer lowers his hands while catching a ball because this increases the time of catch which in turn decreases the momentum since force = (change in momentum) / (time). Therefore he needs to	3

	apply a small force to stop the ball and also the ball exerts a small force on his hands which prevents him from injury.	
28.	**Kepler's Laws of Planetary Motion** **Kepler's laws are stated as follows:** **1. Law of orbits:** ***Each planet moves around the Sun in an elliptical orbit with the Sun at one of the foci.** **2. Law of area:** **The radial vector (line joining the Sun to a planet) sweeps equal areas in equal intervals of time.** 3. **Law of period:** • **The square of the time period of revolution of a planet around the Sun in its elliptical orbit is directly proportional to the cube of the semi-major axis of the ellipse.** • **It can be written as: *** $T^2 \propto a^3$ • T^2 / a^3 = *constant.*	**3**
29.	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	**3**
30.	**Isothermal process**	**3**

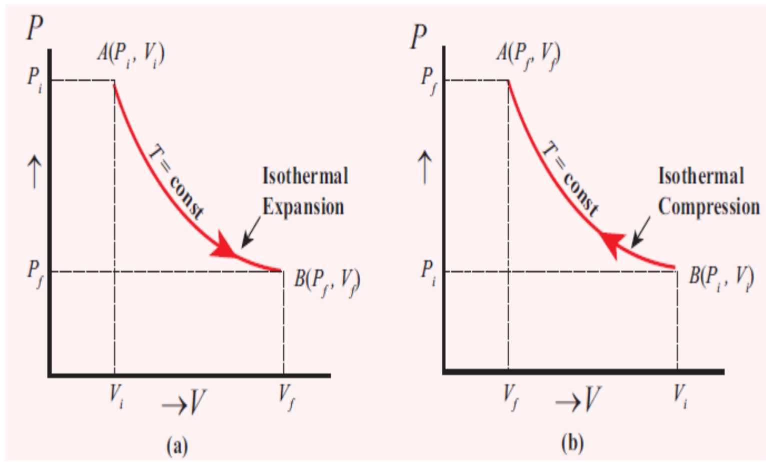
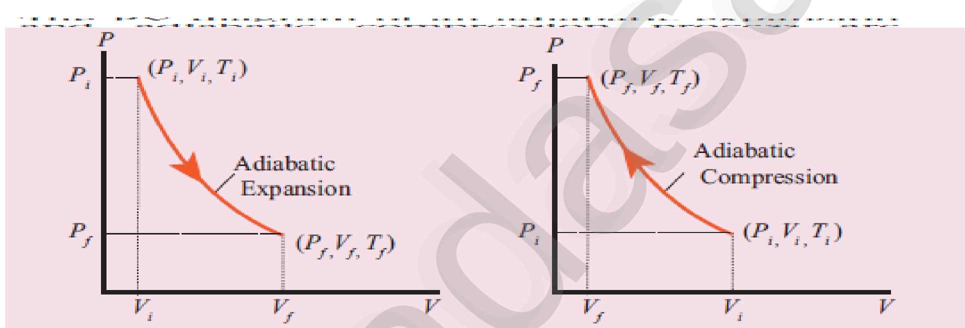


Figure 8.25 (a) Quasi-static isothermal expansion (b) Quasi-static isothermal compression

Adiabatic process



0 PV diagram for adiabatic expansion and adiabatic compression

31. **3**

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. • $T \propto \sqrt{(1/g)}$ *** Independent of the following factors** **(i) Mass of the bob** The time period of oscillation is independent of mass of the simple pendulum. • This is similar to free fall. Therefore, in a pendulum of fixed length, it does not matter whether an elephant swings or an ant swings. • Both of them will swing with the same time period. **(ii) Amplitude of the oscillations** • For a pendulum with small angle approximation (angular displacement is very small), the time period is independent of amplitude of the oscillation.	
32.	**Table 11.1:** Comparison of transverse and longitudinal waves (table below)	**3**

S.No.	Transverse waves	Longitudinal waves
1.	The direction of vibration of particles of the medium is perpendicular to the direction of propagation of waves.	The direction of vibration of particles of the medium is parallel to the direction of propagation of waves.
2.	The disturbances are in the form of crests and troughs.	The disturbances are in the form of compressions and rarefactions.
3.	Transverse waves are possible in elastic medium.	Longitudinal waves are possible in all types of media (solid, liquid and gas).

33.	**Compulsory problem.** **A box is pulled with a force of 25 N to produce a displacement of 15 m. If the angle between the force and displacement is 30o, find the work done by the force.** **Solution** • **Force, F = 25 N** • **Displacement, dr = 15 m** • **Angle between F and dr, θ = 30°** • **Work done, W = Fdr cos θ** • **W = 25 x 15 x cos 30°** • **W = 324.76 J**	**3**

PART-IV

ANSWER 'ALL': 5 X 5 = 25

34. a)	**Errors in Measurement** The uncertainty in a measurement is called an error. Random error, systematic error and gross error are the three possible	**5**

errors.

i) Systematic errors

Systematic errors are reproducible inaccuracies that are consistently in the same direction. These occur often due to a problem that persists throughout the experiment. Systematic errors can be classified as follows

1) Instrumental errors

When an instrument is not calibrated properly at the time of manufacture, instrumental errors may arise. If a measurement is made with a meter scale whose end is worn out, the result obtained will have errors. These errors can be corrected by choosing the instrument carefully.

2) Imperfections in experimental technique or procedure

These errors arise due to the limitations in the experimental arrangement. As an example, while performing experiments with a calorimeter, if there is no proper insulation, there will be radiation losses. This results in errors and to overcome these, necessary correction has to be applied.

3) Personal errors

These errors are due to individuals performing the experiment, may be due to incorrect initial setting up of the experiment or carelessness of the individual making the observation due to improper precautions.

4) Errors due to external causes

The change in the external conditions during an experiment can cause error in measurement. For example, changes in temperature, humidity, or pressure during measurements may affect the result of the measurement

5) Least count error

Least count is the smallest value that can be measured by the measuring instrument, and the error due to this measurement is least count error. The instrument's resolution hence is the cause of this error. Least count error can be reduced by using a high precision instrument for the measurement.

ii) Random errors

Random errors may arise due to random and unpredictable

	variations in experimental conditions like pressure, temperature, voltage supply etc. Errors may also be due to personal errors by the observer who performs the experiment. Random errors are sometimes called **"chance error".** When different readings are obtained by a person every time he repeats the experiment, personal error occurs. For example, consider the case of the thickness of a wire measured using a screw gauge. The readings taken may be different for different trials. In this case, a large number of measurements are made and then the arithmetic mean is taken. Usually this arithmetic mean is taken as the best possible true value of the quantity. Certain procedures to be followed to minimize experimental errors, along with examples. (iv) Using wrong values of the observations in calculations. These errors can be minimized only when an observer is careful and mentally alert. **iii) 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.	
34. b)	Consider an object moving in a straight line with uniform or constant acceleration 'a'. Let u be the velocity of the object at time t = 0, and v be velocity of the body at a later time t. **Velocity - time relation** (i) The acceleration of the body at any instant is given by the first derivative of the velocity with respect to time, $a = \frac{dv}{dt}$ or $dv = a\,dt$	**5**

Integrating both sides with the condition that as time changes from 0 to t, the velocity changes from u to v. For the constant acceleration,

$$\int_u^v dv = \int_0^t a\,dt = a\int_0^t dt \Rightarrow [v]_u^v = a[t]_0^t$$

$$v - u = at \quad (or) \quad v = u + at \qquad \rightarrow (2.7)$$

Displacement – time relation

(ii) The velocity of the body is given by the first derivative of the displacement with respect to time.

$$v = \frac{ds}{dt} \text{ or } ds = vdt$$

and since $v = u + at$,

We get $ds = (u + at)dt$

Assume that initially at time t = 0, the particle started from the origin. At a later time t, the particle displacement is s. Further assuming that acceleration is time-independent, we have

$$\int_0^s ds = \int_0^t u\,dt + \int_o^t at\,dt \;(or)\; s = ut + \frac{1}{2}at^2 \;(2.8)$$

Velocity – displacement relation

(iii) The acceleration is given by the first derivative of velocity with respect to time.

$$a = \frac{dv}{dt} = \frac{dv}{ds}\frac{ds}{dt} = \frac{dv}{ds}v$$

[since ds/dt = v] where s is displacement traversed.

This is rewritten as $a = \frac{1}{2}\frac{d}{ds}(v^2)$

$$\text{or } ds = \frac{1}{2a}d(v^2)$$

Integrating the above equation, using the fact when the velocity changes from u to v, displacement changes from 0 to s, we get

$$\therefore s = \frac{1}{2a}\left(v^2 - u^2\right)$$

$$\therefore v^2 = u^2 + 2as \qquad (2.9)$$

$$\int_0^s ds = \int_u^v \frac{1}{2a}d\left(v^2\right)$$

We can also derive the displacement s in terms of initial velocity u and final velocity v.

From the equation (2.7) we can write,

$$at = v - u$$

Substitute this in equation (2.8), we get

$$s = ut + \frac{1}{2}\left(v - u\right)t$$

$$s = \frac{\left(u + v\right)t}{2} \qquad (2.10)$$

The equations (2.7), (2.8), (2.9) and (2.10) are called

	kinematic equations of motion, and have a wide variety of practical applications. **Kinematic equations** $v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $s = \frac{(u+v)t}{2}$ It is to be noted that all these kinematic equations are valid only if the motion is in a straight line with constant acceleration. For circular motion and oscillatory motion these equations are not applicable	
35. a)	Work and energy are equivalents. This is true in the case of kinetic energy also. To prove this, let us consider a body of mass m at rest on a frictionless horizontal surface. The work (W) done by the constant force (F) for a displacement (s) in the same direction is, W = Fs The constant force is given by the equation, F = ma	**5**

	The third equation of motion (refer section 2.10.3) can be written as, $$v^2 = u^2 + 2as$$ $$a = \frac{v^2 - u^2}{2s}$$ Substituting for a in equation (4.8), $$F = m\left(\frac{v^2 - u^2}{2s}\right) \quad (4.9)$$ Substituting equation (4.9) in (4.7), $$W = m\left(\frac{v^2}{2s}s\right) - m\left(\frac{u^2}{2s}s\right)$$ $$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \quad (4.10)$$	

	The expression for kinetic energy: The term $\left(\frac{1}{2}mv^2\right)$ in the above equation is the kinetic energy of the body of mass (m) moving with velocity (v). $$KE = \frac{1}{2}mv^2 \qquad (4.11)$$ Kinetic energy of the body is always positive. From equations (4.10) and (4.11) $$\Delta KE = \frac{1}{2}mv^2 - \frac{1}{2}mu^2 \qquad (4.12)$$ Thus, $W = \Delta KE$	

	The expression on the right hand side (RHS) of equation (4.12) is the change in kinetic energy (ΔKE) of the body. This implies that *the work done by the force on the body changes the kinetic energy of the body. This is called work-kinetic energy theorem.* **The work-kinetic energy theorem implies the following.** 1. If the work done by the force on the body is positive then its kinetic energy increases. 2. If the work done by the force on the body is negative then its kinetic energy decreases. 3. If there is no work done by the force on the body then there is no change in its kinetic energy, which means that the body has moved at constant speed provided its mass remains constant.	
35. b)	**(i) Parallel axis theorem:** *Parallel axis theorem states that the moment of inertia of a body about any axis is equal to the sum of its moment of inertia about a parallel axis through its centre of mass and the product of the mass of the body and the square of the perpendicular distance between the two axes.*	**5**

If I_C is the moment of inertia of the body of mass M about an axis passing through the centre of mass, then the moment of inertia I about a parallel axis at a distance d from it is given by the relation,

$$I = I_C + Md^2 \quad (5.46)$$

Let us consider a rigid body as shown in Figure 5.25. Its moment of inertia about an axis AB passing through the centre of mass is I_C. DE is another axis parallel to AB at a perpendicular distance d from AB. The moment of inertia of the body about DE is I. We attempt to get an expression for I in terms of I_C. For this, let us consider a point mass m on the body at position x from its centre of mass.

$$I = \sum m(x + d)^2$$

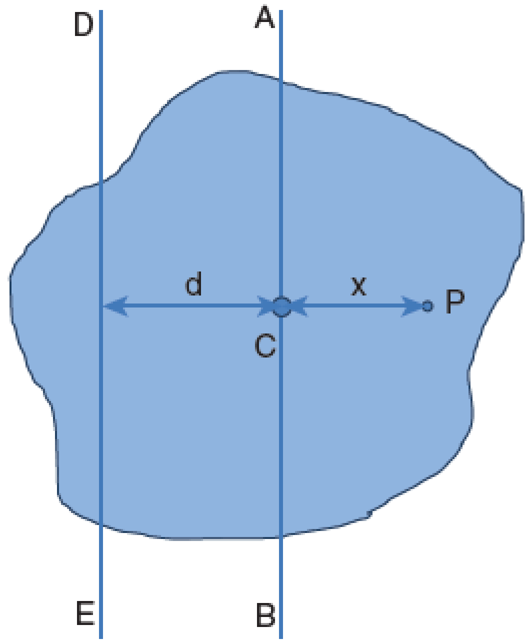


Figure 5.25 Parallel axis theorem

The moment of inertia of the point mass about the axis DE is, $m(x+d)^2$.

The moment of inertia I of the whole body about DE is the summation of the above expression.

Here, $\sum m$ is the entire mass M of the object $\left(\sum m = M\right)$

$$I = I_C + Md^2$$

Hence, the parallel axis theorem is proved.

	This equation could further be written as, $I=\sum m\left(x^2+d^2+2xd\right)$ $I=\sum\left(mx^2+md^2+2dmx\right)$ $I=\sum mx^2+\sum md^2+2d\sum mx$ Here, $\sum mx^2$ is the moment of inertia of the body about the centre of mass. Hence, $I_C=\sum mx^2$ The term, $\sum mx=0$ because, x can take positive and negative values with respect to the axis AB. The summation $\left(\sum mx\right)$ will be zero. Thus, $I=I_C+\sum md^2=I_C+\left(\sum m\right)d^2$	
36. a)	**ESCAPE SPEED** When the object reaches a height far away from Earth and hence treated as approaching infinity, the gravitational potential energy becomes zero $[U(\infty)=0]$ and the kinetic energy becomes zero as well. Therefore the final total energy of the object becomes zero. This is for minimum energy and for minimum speed to escape. Otherwise Kinetic energy can be nonzero.	**5**

When the object reaches a height far away from Earth and hence treated as approaching infinity, the gravitational potential energy becomes zero [$U(\infty)=0$] and the kinetic energy becomes zero as well. Therefore the final total energy of the object becomes zero. This is for minimum energy and for minimum speed to escape. Otherwise Kinetic energy can be nonzero.

Consider an object of mass M on the surface of the Earth. When it is thrown up with an initial speed v_i, the initial total energy of the object is

$$E_i = \frac{1}{2}Mv_i^2 - \frac{GMM_E}{R_E} \quad (6.53)$$

where, M_E is the mass of the Earth and R_E- the radius of the Earth. The term $-\frac{GMM_E}{R_E}$ is the potential energy of the mass M.

	Using $g = \frac{GM_E}{R_E^2}$, $$v_e^{\ 2} = 2gR_E$$ $$v_e = \sqrt{2gR_E} \quad (6.56)$$ From equation (6.56) the escape speed depends on two factors: acceleration due to gravity and radius of the Earth. It is completely independent of the mass of the object. By substituting the values of g (9.8 $m\,s^{-2}$) and $R_e = 6400\,km$, the escape speed of the Earth is $v_e = 11.2\,km\,s^{-1}$. The escape speed is independent of the direction	

Consider the escape speed, the minimum speed required by an object to escape Earth's gravitational field, hence replace v_i *with* v_e. i.e,

$$\frac{1}{2}Mv_e^{\,2} = \frac{GMM_E}{R_E}$$

$$v_e^{\,2} = \frac{GMM_E}{R_E}\cdot\frac{2}{M}$$

$$v_e^{\,2} = \frac{2GM_E}{R_E}$$

$$E_f = 0$$

According to the law of energy conservation,

$$E_i = E_f \qquad (6.54)$$

Substituting (6.53) in (6.54) we get,

$$\frac{1}{2}Mv_i^{\,2} - \frac{GMM_E}{R_E} = 0$$

$$\frac{1}{2}Mv_i^{\,2} = \frac{GMM_E}{R_E} \qquad (6.55)$$

	Using $g = \frac{GM_E}{R_E^2}$, $$v_e^{\ 2} = 2gR_E$$ $$v_e = \sqrt{2gR_E} \qquad (6.56)$$ From equation (6.56) the escape speed depends on two factors: acceleration due to gravity and radius of the Earth. It is completely independent of the mass of the object. By substituting the values of g ($9.8\ m\,s^{-2}$) and $R_e = 6400\,km$, the escape speed of the Earth is $v_e = 11.2\,km\,s^{-1}$. The escape speed is independent of the direction	

in which the object is thrown. Irrespective of whether the object is thrown vertically up, radially outwards or tangentially it requires the same initial speed to escape Earth's gravity. It is shown in Figure 6.19

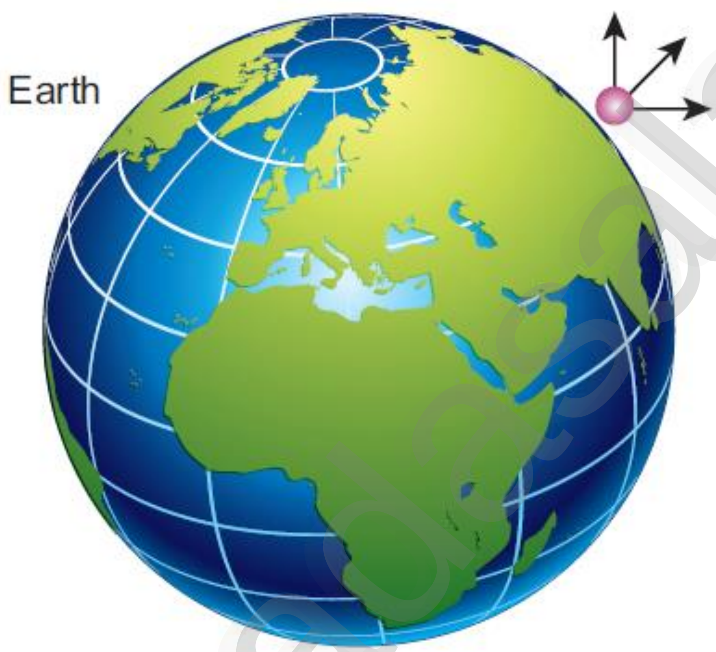


Figure 6.19 Escape speed independent of angle

Lighter molecules such as hydrogen and helium have enough speed to escape from the Earth, unlike the heavier ones such as nitrogen and oxygen. (The average speed of

36. b)		**5**

8.7.2 Meyer's relation

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 (8.20)

$$dU = \mu C_v dT \quad (8.21)$$

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.

$$Q = \mu C_p dT \quad (8.22)$$

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

$$W = PdV \quad (8.23)$$

But from the first law of thermodynamics,

$$Q = dU + W \quad (8.24)$$

Substituting equations (8.21), (8.22) and (8.23) in (8.24), we get,

$$\mu C_p dT = \mu C_v dT + PdV \quad (8.25)$$

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

	$$PV = \mu RT \Rightarrow PdV + VdP = \mu RdT \quad (8.26)$$ Since the pressure is constant, dP=0 $$\therefore C_p dT = C_v dT + RdT$$ $$\therefore C_p = C_v + R \quad \text{(or)} \quad C_p - C_v = R \quad (8.27)$$ 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).	

37. a)	**9.1.2 Postulates of kinetic theory of gases** Kinetic theory is based on certain assumptions which makes the mathematical treatment simple. None of these assumptions are strictly true yet the model based on these assumptions can be applied to all gases. 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.	5

	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 randomly.	

37. b)

10.4.2 Vertical oscillations of a spring

Figure 10.14 Springs

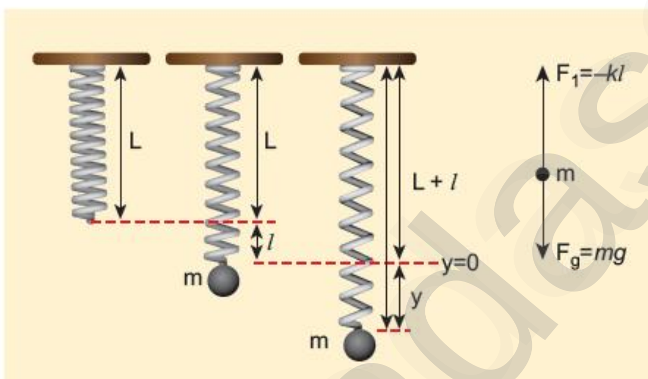


Figure 10.15 A massless spring with stiffness constant k

Let us consider a massless spring with stiffness constant or force constant k attached to a ceiling as shown in Figure 10.15. Let the length of the spring before loading mass m be L. If the block of mass m is attached to the other end of spring, then the spring elongates by a length l. Let F_1 be the restoring force due to stretching of spring. Due to mass m, the gravitational force acts vertically downward.

5

We can draw free-body diagram for this system as shown in Figure 10.15. When the system is under equilibrium,

$$F_1 + mg = 0 \quad (10.27)$$

But the spring elongates by small displacement *l*, therefore,

$$F_1 \propto l \Rightarrow F_1 = -k\,l \qquad (10.28)$$

Substituting equation (10.28) in equation (10.27), we get

$$-k\,l + mg = 0$$

$$\text{mg} = \text{kl}$$

or

$$\frac{m}{k} = \frac{l}{g} \qquad (10.29)$$

Suppose we apply a very small external force on the mass such that the mass further displaces downward by a displacement y, then it will oscillate up and down. Now, the restoring force due to this stretching of spring (total extension of spring is $y + l$) is

$$F_2 \propto (y + l)$$

$$F_2 = -k\,(y + l) = -ky - kl \qquad (10.30)$$

Since, the mass moves up and down with acceleration $\frac{d^2y}{dt^2}$, by drawing the free body diagram for this case, we get

$$-ky - kl + mg = m\frac{d^2y}{dt^2} \qquad (10.31)$$

The net force acting on the mass due to this stretching is

$$F = F_2 + mg$$
$$F = -ky - kl + mg \qquad (10.32)$$

The gravitational force opposes the restoring force. Substituting equation (10.29) in equation (10.32), we get

$$F = -ky - kl + kl = -ky$$

Applying Newton's law, we get

$$m\frac{d^2y}{dt^2} = -k\,y$$
$$\frac{d^2y}{dt^2} = -\frac{k}{m}y \qquad (10.33)$$

The above equation is in the form of simple harmonic differential equation. Therefore, we get the time period as

$$T = 2\pi\sqrt{\frac{m}{k}} \text{ second} \tag{10.34}$$

Note The time period obtained for horizontal oscillations of spring and for vertical oscillations of spring are found to be equal.

The time period can be rewritten using equation (10.29)

$$T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{l}{g}} \text{ second} \tag{10.35}$$

The acceleration due to gravity g can be computed from the formula

$$g = 4\pi^2\left(\frac{l}{T^2}\right) \text{ m s}^{-2} \tag{10.36}$$

Q.No.	Answer	Marks
38. a)	See below	5

11.4.1 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

$$PV = \text{Constant} \qquad (11.20)$$

Differentiating equation (11.20), we get

$$PdV + VdP = 0$$

$$\text{or,} \quad P = -V\frac{dP}{dV} = K_I \qquad (11.21)$$

where, K_I is an isothermal bulk modulus of air. Substituting equation (11.21) in equation

(11.16), the speed of sound in air is

$$v_T = \sqrt{\frac{K_I}{\rho}} = \sqrt{\frac{P}{\rho}} \qquad (11.22)$$

Since P is the pressure of air whose value at NTP (Normal Temperature and Pressure) is 76 cm of mercury, we have $P = h\rho g$

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

$\rho = 1.293\ kg\,m^{-3}$. Here ρ is density of air

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

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

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

But the speed of sound in air at 0°C is experimentally observed as $332\ \mathrm{m\,s^{-1}}$ 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

11.4.2 Laplace's correction

In 1816, 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

$$PV^{\gamma} = \text{constant} \qquad (11.23)$$

where, $\gamma = \frac{C_P}{C_v}$, which is the ratio between specific heat at constant pressure and specific heat at constant volume.

Differentiating equation (11.23) on both the sides, we get

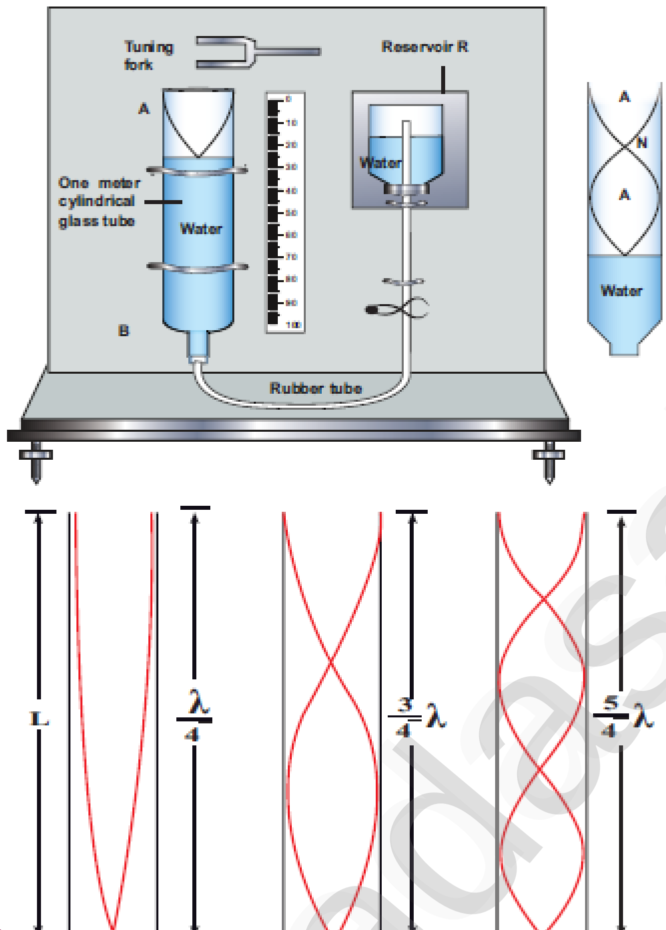
$$V^{\gamma}\, dP + P\,(\gamma V^{\gamma-1}\, dV) = 0$$

or, $$\gamma P = -V\frac{dp}{dV} = K_A \qquad (11.24)$$

where, K_A is the adiabatic bulk modulus of air. Now, substituting equation (11.24) in equation (11.16), the speed of sound in air is

$$v_A = \sqrt{\frac{K_A}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma}\, v_T \qquad (11.25)$$

Since air contains mainly, nitrogen, oxygen, hydrogen etc, (diatomic gas), we take $\gamma = 1.4$. Hence, speed of sound in air is $v_A = (\sqrt{1.4})(280\ \mathrm{m\ s^{-1}}) = 331.30\ \mathrm{m\ s^{-1}}$, which is very much closer to experimental data.

38. b)	**11.10.1 Resonance air column apparatus**  Figure 11.44: The resonance air column apparatus and first, second and third resonance	5

	The resonance air column apparatus is one of the simplest techniques to measure the speed of sound in air at room temperature. It consists of a cylindrical glass tube of one meter length whose one end A is open and another end B is connected to the water reservoir R through a rubber tube as shown in Figure 11.44. This cylindrical glass tube is mounted on a vertical stand with a scale attached to it. The tube is partially filled with	

	water and the water level can be adjusted by raising or lowering the water in the reservoir R. The surface of the water will act as a closed end and other as the open end. Therefore, it behaves like a closed organ pipe, forming nodes at the surface of water and antinodes at the closed end. When a vibrating tuning fork is brought near the open end of the tube, longitudinal waves are formed inside the air column. These waves move downward as shown in Figure 11.44, and reach the surfaces of water and get reflected and produce standing waves. The length of the air column is varied by changing the water level until a loud sound is produced in the air column. At this particular length the frequency of waves in the air column resonates with the frequency of the tuning fork (natural frequency of the tuning fork). At resonance, the frequency of sound waves produced is equal to the frequency of the tuning fork. This will occur only when the length of air column is proportional to $\left(\frac{1}{4}\right)^{th}$ of the wavelength of the sound waves produced.	

Let the first resonance occur at length L_1, then

$$\frac{1}{4}\lambda = L_1 \qquad (11.80)$$

But since the antinodes are not exactly formed at the open end, we have to include a correction, called end correction *e*, by assuming that the antinode is formed at some small distance above the open end. Including this end correction, the first resonance is

$$\frac{1}{4}\lambda = L_1 + e \qquad (11.81)$$

Now the length of the air column is increased to get the second resonance. Let L_2 be the length at which the second resonance occurs. Again taking end correction into account, we have

$$\frac{3}{4}\lambda = L_2 + e \qquad (11.82)$$

In order to avoid end correction, let us take the difference of equation (11.82) and equation (11.81), we get

$$\frac{3}{4}\lambda - \frac{1}{4}\lambda = (L_2 + e) - (L_1 + e)$$

$$\Rightarrow \frac{1}{2}\lambda = L_2 - L_1 = \Delta L$$

$$\Rightarrow \lambda = 2\Delta L$$

The speed of the sound in air at room temperature can be computed by using the formula

$$v = f\lambda = 2f\Delta L$$

Further, to compute the end correction, we use equation (11.81) and equation (11.82), we get

$$e = \frac{L_2 - 3L_1}{2}$$

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