Class XI Session 2023-24
Subject - Physics
Sample Question Paper - 6

Time Allowed: 3 hours **Maximum Marks: 70**

General Instructions:

1. There are 33 questions in all. All questions are compulsory.
2. This question paper has five sections: Section A, Section B, Section C, Section D and Section E. All the sections are compulsory.
3. Section A contains sixteen questions, twelve MCQ and four Assertion Reasoning based of 1 mark each, Section B contains five questions of two marks each, Section C contains seven questions of three marks each, Section D contains two case study-based questions of four marks each and Section E contains three long answer questions of five marks each.
4. There is no overall choice. However, an internal choice has been provided in section B, C, D and E. You have to attempt only one of the choices in such questions.
5. Use of calculators is not allowed.

Section A

1. The unit of a in van der Waal's gas equation is: **[1]**

a) atm L^2 per mol
b) atm L^{-1} mol^{-2}
c) atm L^2 mol^{-2}
d) atm L^{-2} mol^2

2. Equation of plane wave is $y = 4\sin\frac{\pi}{4}\left[2t + \frac{x}{8}\right]$ **[1]**
The phase difference at any given instant of two particles 16 cm apart is

a) 60°
b) 30°
c) 90°
d) 120°

3. If force acts on a body, whose line of action does not pass through its centre of gravity, then the body will experience **[1]**

a) linear acceleration
b) angular acceleration
c) both angular acceleration and linear acceleration
d) none of these

4. For different capillaries of radius r, the condition of liquid rise (h) above the liquid surface is **[1]**

a) $\frac{h}{r}$ = constant
b) h - r = constant
c) h + r = constant
d) rh = constant

5. Two heavy spheres each of mass 100 kg and radius 0.10 m are placed 1.0 m apart on a horizontal table. What is **[1]**

the gravitational force and potential at the midpoint of the line joining the centers of the spheres? Is an object placed at that point in equilibrium? If so, is the equilibrium stable or unstable?

a) 0, 1.9×10^{-8} J/kg, unstable
b) 0, 1.9×10^{-8} J/kg stable
c) 0, 2.7×10^{-8} J/kg, unstable
d) 0, 2.7×10^{-8} J/kg, stable

6. There are three sources of the sound of equal intensities with frequencies 400, 401, and 402 Hz. The number of beats per seconds is: **[1]**

a) 2
b) 0
c) 1
d) 3

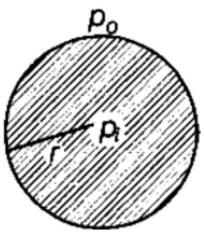
7. For the one-dimensional motion, described by x = t–sin t **[1]**

a) x (t) > 0 for all t > 0
b) v (t) lies between 0 and 2.
c) a (t) > 0 for all t > 0
d) v (t) > 0 for all t > 0

8. A standing wave is represented by: **[1]**
y = a sin (100t) cos (0.01x),
where y and a are in millimetre, t in second and x in metre. Velocity of wave is:

a) not derived
b) 1 m/s
c) 10^4 m/s
d) 10^{-4} m/s

9. In figure, pressure inside a spherical drop is more than pressure outside. (S = surface tension and r = radius of bubble) **[1]**



The extra surface energy if radius of bubble is in creased by Δr is

a) $2\pi r\ \Delta r\ S$
b) $4\pi r\ \Delta r\ S$
c) $10\pi r\ \Delta r\ S$
d) $8\pi r\ \Delta r\ S$

10. A ball is dropped from a spacecraft revolving around the earth at a height of 120 km. What will happen to the ball? **[1]**

a) it will continue to move with the same speed along the original orbit of spacecraft
b) it will go very far in the space
c) it will fall down to the earth gradually
d) it will move with the same speed tangentially to the spacecraft

11. If a gymnast sitting on a rotating stool with his arms outstretched, suddenly lowers his hands: **[1]**

a) The angular velocity decreases
b) His moment of inertia decreases
c) The angular momentum increases
d) The angular velocity stays constant

12. For an enclosure maintained at 1,000 K, the maximum radiation occurs at wavelength λ_m. If the temperature is raised to 2,000 K, the peak will shift to **[1]**

a) $\frac{\lambda_m}{2}$
b) $\frac{3\lambda_m}{2}$
c) $\frac{5\lambda_m}{2}$
d) $\frac{7\lambda_m}{2}$

13. **Assertion (A):** A person working on in horizontal road with a load on his head does no work. **[1]**

Reason (R): No work is said to be done if directions of force and displacement of load are perpendicular to each other.

a) Both A and R are true and R is the correct explanation of A.
b) Both A and R are true but R is not the correct explanation of A.
c) A is true but R is false.
d) A is false but R is true.

14. **Assertion:** The temperature of a gas rises during an adiabatic compression, although no heat is given from outside. **[1]**

Reason: During adiabatic compression pressure of gas decreases.

a) Assertion and reason both are correct statements and reason is correct explanation for assertion.
b) Assertion and reason both are correct statements but reason is not correct explanation for assertion.
c) Assertion is correct statement but reason is wrong statement.
d) Assertion is wrong statement but reason is correct statement.

15. **Assertion:** Earth is continuously pulling moon towards its centre but moon does not fall to earth. **[1]**

Reason: Attraction of sun on moon is greater than that of earth on moon.

a) Assertion and reason both are correct statements and reason is correct explanation for assertion.
b) Assertion and reason both are correct statements but reason is not correct explanation for assertion.
c) Assertion is correct statement but reason is wrong statement.
d) Assertion is wrong statement but reason is correct statement.

16. **Assertion (A):** Minimum number of vectors having unequal magnitude in a plane required to give zero resultant is three. **[1]**

Reason (R): If vector addition of three vectors is zero, then they must lie in a plane.

a) Both A and R are true and R is the correct explanation of A.
b) Both A and R are true but R is not the correct explanation of A.
c) A is true but R is false.
d) A is false but R is true.

Section B

17. Find the ratio of velocity of sound in hydrogen gas ($\gamma = \frac{7}{5}$) to that in helium gas ($\gamma = \frac{5}{3}$) at the same temperature. Given that molecular weights of hydrogen and helium are 2 and 4 respectively. **[2]**

18. Find an expression for viscous force F acting on a tiny steel ball of radius r moving in a viscous liquid of viscosity η with a constant speed ν by the method of dimensional analysis. **[2]**

19. The orbital velocity ν of a satellite may depend on its mass m, distance r from the centre of earth and acceleration due to gravity g. Obtain an expression for orbital velocity. **[2]**

20. An elevator and its load weigh a total of 800 kg. Find the tension T in the supporting cable when the elevator, originally moving downwards at 20 ms^{-1} is brought to rest with constant retardation in a distance of 50 m. **[2]**

21. Are we living at the bottom of a gravitational well? Give reason. **[2]**

OR

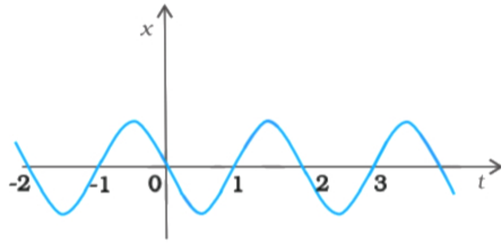
Explain why a tennis ball bounces higher on hills than in plane.

Section C

22. In Millikan's oil drop experiment, what is the terminal speed of an uncharged drop of radius 2.0×10^{-5}m and density 1.2×10^{3} kgm^{-3}? Take the viscosity of air at the temperature of the experiment to be 1.8×10^{-5} Pa s. How much is the viscous force on the drop at that speed? Neglect buoyancy of the drop due to air. **[3]**

23. A **thermacole** icebox is a cheap and efficient method for storing small quantities of cooked food in summer in particular. A cubical icebox of side 30 cm has a thickness of 5.0 cm. If 4.0 kg of ice is put in the box, estimate the amount of ice remaining after 6 h. The outside temperature is 45^{o}C, and co-efficient of thermal conductivity of thermacole is 0.01 J s^{-1}m^{-1}K^{-1}. [Heat of fusion of water = 335×10^{3} J kg^{-1}] **[3]**

24. Figure gives the x-t plot of a particle executing one-dimensional simple harmonic motion. Give the signs of position, velocity and acceleration variables of the particle at t = 0.3 s, 1.2 s, -1.2 s. **[3]**



25. A batsman deflects a ball by an angle of 45° without changing its initial speed which is equal to 54 km/h. What is the impulse imparted to the ball? (Mass of the ball is 0.15 kg.) **[3]**

26. What is meant by a reversible heat engine? Explain why a reversible engine is most efficient. **[3]**

27. A hammer of mass 1 kg strikes on the head of a nail with a velocity of 10 ms^{-1}. It drives the nail 1 cm into a wooden block. Calculate the force applied by the hammer and the time of impact. **[3]**

28. A liquid is kept in a cylindrical vessel that is being rotated about its axis. The liquid rises at the sides. If the radius of the vessel is 0.05 m and the speed of rotation is 2 rps, find the difference in the heights of the liquid at the centre of the vessel and at its sides. **[3]**

OR

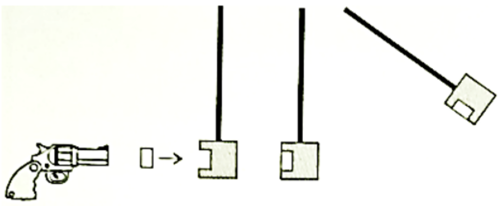
What is terminal velocity and derive an expression for it?

Section D

29. **Read the text carefully and answer the questions:** **[4]**

The ballistic pendulum was invented in 1742 by English mathematician Benjamin Robins.

A Ballistic Pendulum is a device for measuring a bullet's momentum and speed by employing perfectly inelastic collision.



A large wooden block suspended by two cords serves as the pendulum bob. When a bullet is fired into the bob, it gets embedded in the bob and its momentum is transferred to the bob.

The bullet's momentum and velocity can be determined from the amplitude of the pendulum swing. The velocity of the bullet, in turn, can be derived from its calculated momentum.

After collision, if the pendulum reaches a height h, then from principle of conservation of mechanical energy

$\frac{1}{2}(m+M)v_p^2$ = (m + M)gh

where, m= mass of bullet, M = mass of the bob v_P = velocity of the bob-bullet combination

$\therefore v_p = \sqrt{2gh}$

Now, Momentum before collision = Momentum after collision

$mv_B = (m+M)v_p$

where, v_B = velocity of bullet

$v_B = \frac{m+M}{m}\sqrt{2gh}$

the ballistic pendulum used to be a common tool for the determination of the muzzle velocity of bullets as a measure of the performance of firearms and ammunition (Nowadays, the ballistics pendulum has been replaced by the ballistic chronograph, an electronic device).

(i) In ballistic pendulum the collision is

a) Perfectly inelastic
b) Partly elastic, partly inelastic
c) Elastic
d) Inelastic

(ii) Which two principles of Physics are applied to find the velocity of the bullet?

a) conservation of mass and conservation of momentum
b) conservation of mechanical energy, conservation of momentum and conservation of mass
c) conservation of mechanical energy and conservation of momentum
d) conservation of mechanical energy and conservation of mass

(iii) The ballistic pendulum was invented by a

a) Chemist
b) Warrior
c) Mathematician
d) Physicist

OR

A ballistic pendulum of 1 kg is fired with a bullet of mass 1 g. If the pendulum rises 2 cm, find the velocity of the bullet.

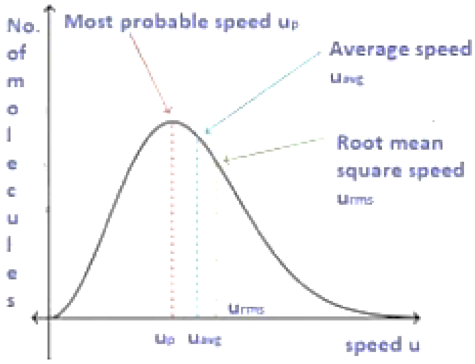
a) 6330 m/s
b) 0.633 m/s
c) 12.65 m/s
d) 633 m/s

(iv) Ballistic pendulum has been replaced by

a) Gyrograph
b) Seismograph
c) Tachograph
d) Chronograph

30. **Read the text carefully and answer the questions:** **[4]**

Root mean square velocity (RMS value)is the square root of the mean of squares of the velocity of individual gas molecules and the Average velocity is the arithmetic mean of the velocities of different molecules of a gas at a given temperature.



(i) Moon has no atmosphere because:

a) the escape velocity of the moon's surface is more than the r.m.s velocity of all molecules

b) it is far away from the surface of the earth

c) the r.m.s. velocity of all the gas molecules is more than the escape velocity of the moon's surface

d) its surface temperature is 10^oC

(ii) For an ideal gas, $\frac{C_P}{C_V}$ is

a) ≤ 1

b) none of these

c) > 1

d) < 1

(iii) The root means square velocity of hydrogen is $\sqrt{5}$ times that of nitrogen. If T is the temperature of the gas then:

a) $T(H_2) = T(N_2)$

b) $T(H_2) < T(N_2)$

c) none of these

d) $T(H_2) > T(N_2)$

(iv) Suppose the temperature of the gas is tripled and N_2 molecules dissociate into an atom. Then what will be the rms speed of atom:

a) none of these

b) $v_0\sqrt{6}$

c) $v_0\sqrt{3}$

d) v_0

OR

The velocities of the molecules are v, 2v, 3v, 4v & 5v. The RMS speed will be:

a) 11 v

b) $v(12)^{11}$

c) v

d) $v(11)^{12}$

Section E

31. The motion of a particle executing simple harmonic motion is described by the displacement function, $x(t) = A\cos(\omega t + \phi)$ If the initial (t = 0) position of the particle is 1 cm and its initial velocity is ω cm /s, then what are its amplitude and initial phase angle? The angular frequency of the particle is π s^{-1}. If instead of the cosine function, we choose the sine function to describe the SHM, $x = B\sin(\omega t + \phi)$, then what are the amplitude and initial phase of the particle with the above initial conditions? **[5]**

OR

Using the correspondence of S.H.M. and uniform circular motion, find displacement, velocity, amplitude, time period and frequency of a particle executing S.H.M?

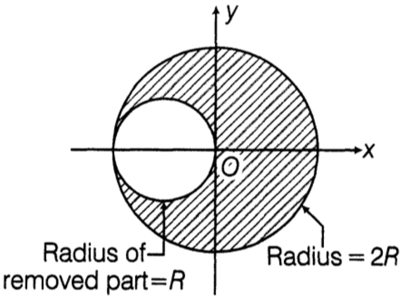
32. A vector has magnitude and direction. Does it have a location in space? Can it vary with time? Will two equal vectors a and b at different locations in space necessarily have identical physical effects? Give examples in support of your answer. **[5]**

OR

A quarterback, standing on his opponents 35-yard line, throws a football directly down field, releasing the ball at a height of 2.00 m above the ground with an initial velocity of 20.0 m/s, directed 30.0° above the horizontal.

i. How long does it take for the ball to cross the goal line, 32.0 m from the point of release?
ii. The ball is thrown too hard and so passes over the head of the intended receiver at the goal line. What is the ball's height above the ground as it crosses the goal line?

33. A disc of radius R is removed from a disc of radius 2R as shown. **[5]**



Find centre of mass of above disc with hole.

OR

Two cylindrical hollow drums of radii R and 2R, and of a common height h, are rotating with angular velocities ω_1 (anti-clockwise) and ω_2 (clockwise), respectively. Their axes, fixed are parallel and in a horizontal plane separated by $(3R+\delta)$. They are now brought in contact $(\delta \rightarrow 0)$.

i. Show the frictional forces just after contact.
ii. Identify forces and torques external to the system just after contact.
iii. What would be the ratio of final angular velocities when friction ceases?

Solution

Section A

1. **(a)** atm L^2 per mol

   Explanation: Van der Wall's equation is

   $\left(P+\frac{a}{V^2}\right)(V-b)=RT$

   $\therefore$ [P] = $\left[\frac{a}{V^2}\right]$ or [a] = [P][V^2]

   Unit of a = atm L^2 per mole.

2. **(c)** 90°

   Explanation: $y=4\sin\left[\frac{2\pi}{4}t+\frac{\pi}{32}x\right]$

   $y=A\sin\left[\frac{2\pi}{T}t+\frac{2\pi}{\lambda}x\right]$

   $\Delta\phi=\frac{2\pi}{\lambda}\Delta x=\frac{\pi}{32}\times 16=\frac{\pi}{2}$

3. **(c)** both angular acceleration and linear acceleration

   Explanation: The body will experience both linear and angular accelerations.

4. **(d)** rh = constant

   Explanation: h = $\frac{2\sigma\cos\theta}{r\rho g}$

   For a given liquid-solid pair,

   hr = $\frac{2\sigma\cos\theta}{\rho g}$ = constant

5. **(c)** 0, 2.7 $\times$ 10^{-8} J/kg, unstable

   Explanation: Here, G = 6.67 $\times$ 10^{-11}N m^2 kg^{-2}

   M = 100 kg

   R = 0.1 m

   Distance between the two spheres d = 1.0 m

   Suppose that the distance of either sphere from the midpoint of the line joining their centre is r. Then

   r = $\frac{d}{2}$ = 0.5 m

   The gravitational field at the midpoint due to two spheres will be equal and opposite.

   Hence, the resultant gravitational field at the midpoint = 0

   The gravitational potential at the midpoint.

   $=\left(\frac{-GM}{r}\right)\times 2$

   $=-\frac{6.67\times 10^{-11}\times 100\times 2}{0.5}$

   = −2.7 $\times$ 10^{-8} Jkg^{-1}

   As the effective force on the body placed at the midpoint is zero, so the body is in equilibrium, if the body is displaced a little towards either mass body from its equilibrium position, it will not return to its initial position of equilibrium. Hence, the body is in unstable equilibrium.

6. **(c)** 1

   Explanation: Beat frequency formula for calculating the beat between two overlapping sound waves is f_b = f_1 - f_2 (f_1 & f_2 are two incident sound waves).

   f_1 = 402 - 401 = 1 Hz

f_2 = 402 - 400 = 2 Hz

F_b = 2 - 1 = 1 Hz

7. **(a)** x (t) > 0 for all t > 0

Explanation: For x(t) > 0 for t > 0

x(t) = t - sint > 0

sint < t

Dividing by t on both sides, this wouldn't affect the inequality, since we have assumed t > 0.

$\frac{\sin t}{t}$ < 1

This is always true for any t > 0

8.

(c) 10^4 m/s

Explanation: y = A sin (100t) cos (0.01x)

$y = A\sin\left(\frac{2\pi}{T}t\right)\cos\left(\frac{2\pi}{\lambda}x\right)$

$\therefore \frac{2\pi}{T} = 100$ or T = $\frac{\pi}{50}$

$\frac{2\pi}{\lambda} = 0.01$ or $\lambda = 200\pi$

$v = \frac{\lambda}{T} = \frac{200\pi}{\frac{\pi}{50}} = 10^4 \text{ m/s}$

9.

(d) $8\pi r\ \Delta r\ S$

Explanation: Suppose a spherical drop of radius r is in equilibrium. If its radius increases by Δr . The extra surface energy is $\left|4\pi(r+\Delta r)^2 - 4\pi r^2\right| S = 8\pi r \Delta r S$

10. **(a)** it will continue to move with the same speed along the original orbit of spacecraft

Explanation: In the absence of any external torque, the ball will continue to move with the same speed along the original orbit of spacecraft.

11.

(b) His moment of inertia decreases

Explanation: When gymnast lowers his hand the distance of the mass from rotational axis decrease. Hence his moment of inertia decreases and angular velocity increases to conserve angular momentum.

12. **(a)** $\frac{\lambda_m}{2}$

Explanation: $\frac{\lambda'_m}{\lambda_m} = \frac{T}{T'} = \frac{1000}{2000} = \frac{1}{2}$

$\lambda'_m = \frac{\lambda_m}{2}$

13. **(a)** Both A and R are true and R is the correct explanation of A.

Explanation: The work done, W = $\vec{F} \cdot \vec{s}$ = Fscosθ, when a person walks on a horizontal road with a load on his head than θ = 90^o. Hence W = Fs cos 90^o = 0

Thus no work is done by the person.

14.

(c) Assertion is correct statement but reason is wrong statement.

Explanation: Assertion is correct statement but reason is wrong statement.

15.

(c) Assertion is correct statement but reason is wrong statement.

Explanation: Assertion is correct statement but reason is wrong statement.

16.

(b) Both A and R are true but R is not the correct explanation of A.

Explanation: Both A and R are true but R is not the correct explanation of A.

Section B

17. $v = \sqrt{\frac{\gamma RT}{M}}$

At constant temperature, $\frac{v_{\mathrm{H}}}{v_{\mathrm{He}}} = \sqrt{\frac{\gamma_{\mathrm{H}}}{\gamma_{\mathrm{He}}} \cdot \frac{M_{\mathrm{He}}}{M_{\mathrm{H}}}}$

$= \sqrt{\frac{7/5}{5/3} \cdot \frac{4}{2}} = \sqrt{\frac{42}{25}} = 1.68$

18. It is given that viscous force F depends on (i) the radius r of steel ball, (ii) the Speed ν of the tiny steel ball, and (iii) the coefficient of viscosity η of viscous liquid.

    Wriring dimensional formula for given quantities, we have

    F = $[MLT^{-1}]$, r = [L], $\nu=[LT^{-1}]$ and

    $\eta = [M^1L^{-1}T^{-1}]$,

    According to given condition we can write

    $[M^1L^1T^{-2}] = [L]^a[M^0L^1T^{-1}]^b[ML^{-1}T^{-1}]^c$

    $= [M^cL^{a-b-c}T^{-b-c}]$

    Comparing powers of M, L and T on either side of equation, we get

    c = 1

    a + b - c = 1

    - b - c = -2

    On solving, these above equations, we get

    a = 1, b = 1 and c = 1

    Hence, the relation becomes

    $f = kr\eta\nu$

    Here, k is constant of proportionality.

19. Let the orbital velocity of satellite be given by the relation

    $v = km^ar^bg^c$

    where, k is a dimensionless constant and a, b, c are unknown powers.

    Writing dimensions on two sides of equation, we have

    $[M^0L^1T^{-1}] = [M]^a[L]^b[LT^{-2}]^c = [M^aL^{b+c}T^{-2c}]$

    By equating the powers on both sides, we have

    a = 0, b + c = 1, -2c = -1

    On solving these equations, we get

    a = 0, $b = +\frac{1}{2}$ and $c = +\frac{1}{2}$

    $v = kr^{1/2}g^{1/2}$

    $\Rightarrow v = k\sqrt{rg}$, which is the required expression.

20. Here, m = 800 kg, T = ?

    u = 20m/s, υ = 0, s = 50m

    From $\upsilon^2 - u^2 = 2as$

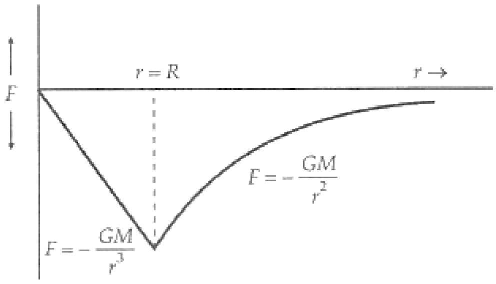
    $a = \frac{v^2-u^2}{2s} = \frac{0-400}{2\times50}$ = $-4 m/s^2$

    As elevator is moving downwards

    $\therefore$ T = m(g - a) = 800(9.8 + 4)N

    $= 1.104 \times 10^4$ N

21. Yes, we are living at the bottom of a gravitational well. Figure shows the variation of gravitational force F with distance r from the centre of the earth. Clearly, the graph has a force minimum at the surface of the earth (r = R).



OR

Let u be the velocity of the tennis ball with which it bounces at a place , where acceleration due to gravity is g’ . The ball will go up till its velocity becomes zero . If h is the height up to which the ball rises up at a place , then initial K.E. of the ball is equal to final P.E. of the ball at highest point .

$(\frac{1}{2})mv^2 = mg'h$

$h = \frac{u^2}{2g'}$

As acceleration due to gravity (g')on hill is less than that on the surface of earth (due to altitude effect), so the ball will bounce higher on hills than on planes .

Section C

22. Terminal speed = 5.8 $\frac{cm}{s}$; Viscous force = 3.9 $\times$ 10^{-10} N

Radius of the given uncharged drop, r = 2.0 $\times$ 10^{-5}m

Density of the uncharged drop, ρ = 1.2 $\times$ 10^3 kgm^{-3}

Viscosity of air, η = 1.8 $\times$ 10^{-5} Pa s

Density of air (P_0) can be taken as zero in order to neglect buoyancy of air.

Acceleration due to gravity, g = 9.8 $\frac{\mathrm{m}}{\mathrm{s}^2}$

Terminal velocity (v) is given by the relation:

$v = \frac{2r^2 \times (\rho - \rho_0) g}{9\eta}$

$v = \frac{2 \times (2.0 \times 10^{-5})(1.2 \times 10^3 - 0) 9.8}{9 \times 1.8 \times 10^{-5}}$

= 5.807 $\times$ 10^{-2} ms^{-1}

= 5.8 ms^{-1}

Hence, the terminal speed of the drop is 5.8 cm s^{-1}

The viscous force on the drop is given by:

F = $5\pi\eta r v$

$\therefore$ F = 6 $\times$ 3.14 $\times$ 1.8 $\times$ 10^{-5} $\times$ 2.0 $\times$ 10^{-5} $\times$ 5.8 $\times$ 10^{-2}

= 3.9 $\times$ 10^{-10} N

Hence, the viscous force on the drop is 3.9 $\times$ 10^{-10} N.

23. Side of the given cubical ice box is given by, s = 30 cm = 0.3 m

Thickness of the ice box is given by, l = 5.0 cm = 0.05 m

Mass of ice kept in the ice box is given by, m = 4 kg

Time gap, t = 6 h $= 6 \times 60 \times 60 s$

Outside temperature is given by, T_1= 45°C

Inside temperature, T_2 = temperature of ice = 0℃

Coefficient of thermal conductivity of thermacole is given by, K = 0.01 J $s^{-1}m^{-1}K^{-1}$

Latent heat of fusion of water is given by, $L = 335 \times 10^3 J\mathrm{kg}^{-1}$

Let m' be the total amount of ice that melts in 6 h.

Total amount of heat lost, θ in 6 hours by the food(mathematical form of the equation comes from the definition of the thermal conductivity):

$\theta = \frac{KA(T_1 - T_2)t}{l}$

Where,

A= Total surface area of the box = 6 × Surface area of each surface of the box= $6s^2 = 6 \times (0.3)^2 = 0.54\mathrm{m}^2$

$\therefore \theta = \frac{0.01 \times 0.54 \times (45) \times 6 \times 60 \times 60}{0.05} = 104976 J$

But $\theta = m' L$, from the definition of latent heat of melting of ice.

$\therefore m' = \frac{\theta}{L}$

$= \frac{104976}{335 \times 10^3} = 0.313\mathrm{kg}$

Mass of ice left is given by = Mass of ice initially kept inside the box - Mass of ice melted in 6hrs = 4 - 0.313 = 3.687 kg

Hence, the amount of ice remaining after 6 h is 3.687 kg.

24. For simple harmonic motion (SHM) of a particle, acceleration (a) is given by the relation:

a = $-\omega^2 x$.....(i)

where ω angular frequency and $x =$ displacement

and velocity of the particle, v = $\frac{dx}{dt}$ .....(ii)

where $\frac{dx}{dt} =$ slope of x-t plot

Now at t = 0.3 s

In this time interval, x is negative. Thus, the slope of the x-t plot will also be negative. From equation (ii) again, velocity is the slope of x-t plot. Therefore, both position and velocity are negative. However, using equation (i), acceleration of the particle will be positive.

Now at t = 1.2 s

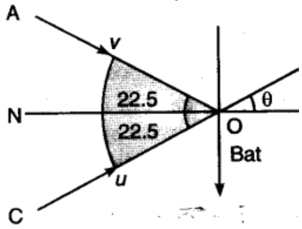
In this time interval, x is positive. Thus, the slope of the x-t plot i.e. the velocity of the particle will also be positive from equation (ii).

Therefore, both position and velocity are positive. However, using equation (i), acceleration of the particle comes to be negative.

And at t = -1.2 s

In this time interval, x is negative and t is also negative. Hence, the slope of the x-t plot i.e. the velocity of the particle will be positive here from equation (ii). From equation (i), it can be inferred that the acceleration of the particle will be positive, as x is negative.

25. The ball struck by the bat is deflected back such that the total angle is 45^{o}.



Now, initial momentum of ball = mu cos θ

$= \frac{0.15\times54\times1000\times\cos 22.5}{3600}$

= 0.15 $\times$ 15 $\times$ 0.9239 along ON

Final momentum of ball = mucos θ along ON

Impulse = change in momentum

= mucos θ - (-mucos θ)

= 2mucos θ

$= 2\times0.15\times15\times0.9239$

i.e., Impulse = 4.16 kg ms^{-1}

26. A reversible heat engine is an engine, which working in a cyclic process, continuously transforms heat into mechanical work such that the processes taking place in the engine are completely reversible.

A reversible heat engine operating between a given pair of hot and cold heat reservoirs is most efficient as compared to other engines because the engine is free from all imperfections of an actual (non-reversible) engine and there is no dissipation of energy due to any cause, whatsoever. In fact, the efficiency of a reversible engine is a function of only the temperatures of two reservoirs and does not depend even on the working substance.

27. It is given that the mass of hammer M = 1 kg and hammer strikes the nail with a velocity of 10 ms^{-1} . As mass of nail is extremely small, hence nail also start moving with same velocity.

Thus, for nail u = 10 ms^{-1}, v = 0 and distance covered, s = 1 cm = 0.01 m.

By using the relation $v^2 - u^2 = 2as$, we have

$(0)^2 - (10)^2 = 2\times a\times(0.01)$

$\Rightarrow a = -\frac{10\times10}{2\times0.01} = -5\times10^3 \text{ms}^{-2}$ ....(1)

Now using the relation v = u + at, we obtain

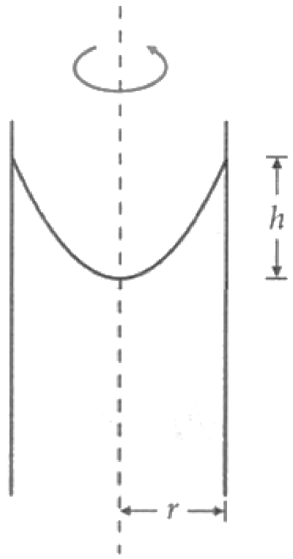
0 = 10 - 5 $\times$ 10^3 . t [by using equation (1)]

$\Rightarrow t = \frac{10}{5\times10^3} = 2\times10^{-3}\text{s}$ or 2 ms

Therefore, Force exerted by the hammer on the nail = $\frac{\Delta p}{\Delta t} = \frac{Mu-0}{\Delta t} = \frac{1\times10}{2\times10^{-3}} = 5\times10^3\text{N}$

28. According to Bernoulli's theorem, we have p + $\frac{1}{2}\rho v^2$ = constant

When the liquid rotates, the velocity at the sides is higher so the pressure is lower. Since the pressure on a given horizontal level must be the same, the liquid rises at the sides to height h to compensate for this drop in pressure.



$\therefore \frac{1}{2}\rho v^2 = h\rho g$

or h = $\frac{v^2}{2g} = \frac{(2\pi r v)^2}{2g} = \frac{2\pi^2 r^2 v^2}{g}$ [$\because$ v = ωr = 2πvr]

But r = 0.05 m, v = 2 rps

$\therefore$ h = $\frac{2\times 9.87\times (0.05)^2\times 2^2}{9.8}$ = 0.02 m

OR

Terminal velocity is the maximum constant velocity acquired by the body which is falling freely in a viscous medium, due to the balanced net downward force acting on the body with the upward resistive viscous force offered by the medium on the body.

When a small spherical body falls freely through a viscous medium then 3 forces act on it:-

i. Weight of body acting vertically downwards.
ii. Up thrust due to buoyancy = weight of fluid displaced by the body, acting upwards.
iii. Viscous drag (F_V) or resistive viscous force acting in the direction opposite to the motion of body.

Let ρ = Density of the material of the spherical body

r = Radius of the spherical body

σ = Density of the viscous medium.

$\therefore$ True weight of the body = W = volume of the body $\times$ density of the body $\times$ g

$\therefore W = \frac{4}{3}\pi r^3 \rho g$

Up ward thrust by the fluid, F_T = weight of medium displaced by the spherical body = volume of the body × density of the viscous medium × g

$= \frac{4}{3}\pi r^3 \sigma g$

Say, v_T = Terminal velocity of body

According to Stoke’s law, viscous drag or viscous force,

$F_V = 6\pi\eta v_T$ (η being coefficient of viscosity of the medium)

When the body attains terminal velocity v_T, then

$F_T + F_V = W$

$\Rightarrow \frac{4}{3}\pi r^3 \sigma g + 6\pi\eta r v_T = \frac{4}{3}\pi r^3 \rho g$

$\therefore v_T = \frac{2r^2(\rho-\sigma)g}{9\eta}$

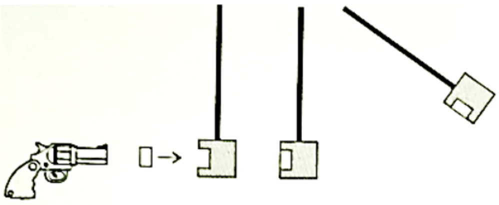
i. v_T directly depends on radius of body and difference of the pressure of material and medium.
ii. v_T inversely depends of co-efficient of viscosity of the medium.

Section D

29. **Read the text carefully and answer the questions:**

The ballistic pendulum was invented in 1742 by English mathematician Benjamin Robins.

A Ballistic Pendulum is a device for measuring a bullet's momentum and speed by employing perfectly inelastic collision.



A large wooden block suspended by two cords serves as the pendulum bob. When a bullet is fired into the bob, it gets embedded in the bob and its momentum is transferred to the bob.

The bullet's momentum and velocity can be determined from the amplitude of the pendulum swing. The velocity of the bullet, in turn, can be derived from its calculated momentum.

After collision, if the pendulum reaches a height h, then from principle of conservation of mechanical energy

$\frac{1}{2}(m+M)v_p^2$ = (m + M)gh

where, m= mass of bullet, M = mass of the bob v_P = velocity of the bob-bullet combination

$\therefore v_p = \sqrt{2gh}$

Now, Momentum before collision = Momentum after collision

$mv_B = (m+M)v_p$

where, v_B = velocity of bullet

$v_B = \frac{m+M}{m}\sqrt{2gh}$

the ballistic pendulum used to be a common tool for the determination of the muzzle velocity of bullets as a measure of the performance of firearms and ammunition (Nowadays, the ballistics pendulum has been replaced by the ballistic chronograph, an electronic device).

(i) **(a)** Perfectly inelastic

Explanation: A large wooden block suspended by two cords serves as the pendulum bob.

When a bullet is fired into the bob, it gets embedded in the bob and its momentum is transferred to the bob. Hence the collision is perfectly inelastic.

(ii) **(c)** conservation of mechanical energy and conservation of momentum

Explanation: Principle of conservation of mechanical energy, an expression for the bob-bullet combination after collision is derived. Then the principle of conservation of momentum is applied to find the velocity of the bullet before collision.

(iii) **(c)** Mathematician

Explanation: The ballistic pendulum was invented in 1742 by English mathematician Benjamin Robins.

OR

(d) 633 m/s

Explanation: $v_B = \frac{m+\mathrm{M}}{m}\sqrt{2gh}$

Putting, m = 1g = 0.001 kg

M = 1 kg

g = 10 m/s^2

h = 2 cm = 0.02 m

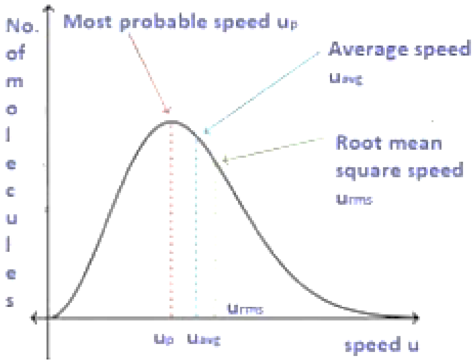
$v_\mathrm{B} = \frac{0.001+1}{0.001}\sqrt{2\times 10\times 0.02}$ = 633 m/s

(iv) **(d)** Chronograph

Explanation: The ballistic pendulum. has now been replaced by the ballistic chronograph, an electronic device.

30. **Read the text carefully and answer the questions:**

Root mean square velocity (RMS value)is the square root of the mean of squares of the velocity of individual gas molecules and the Average velocity is the arithmetic mean of the velocities of different molecules of a gas at a given temperature.



(i) **(c)** the r.m.s. velocity of all the gas molecules is more than the escape velocity of the moon's surface
Explanation: The r.m.s. velocity of all the gas molecules is more than the escape velocity of the moon's surface.

(ii) **(c)** > 1
Explanation: > 1

(iii) **(b)** $T(H_2) < T(N_2)$
Explanation: $T(H_2) < T(N_2)$

(iv) **(b)** $v_0\sqrt{6}$
Explanation: $v_0\sqrt{6}$

OR

(d) $v(11)^{12}$
Explanation: $v(11)^{12}$

Section E

31. Given, displacement equation x(t) = Acos$(\omega t + \phi)$ ...(i)
At t = 0; x(0) = 1 cm, velocity of the particle v = ωcm/s
Angular frequency $\omega = \pi$ s^{-1}
$\Rightarrow 1 = A\cos(\omega t + \phi)$
For t = 0, 1 = A cosϕ..........(i)
Now, $v(t) = \frac{dx(t)}{dt} = \frac{d}{dt}A\cos(\omega t + \phi)$
$= -A\omega\sin(\omega t + \phi)$
Again at t = 0, $v = \omega$ cm/s
$\Rightarrow \omega = -A\omega\sin\phi$
$\Rightarrow -1 = A\sin\phi$ ....(ii)
Squaring and adding eqs.(i) and (ii),
$A^2\cos^2\phi + A^2\sin^2\phi = (1)^2 + (-1)^2$
$A^2 = 2 \Rightarrow A = \pm\sqrt{2}$cm
Hence, the amplitude of the SHM = $\sqrt{2}$ cm
Dividing Eq. (ii) by (i), we get
$\frac{A\sin\phi}{A\cos\phi} = \frac{-1}{1}$ or $\tan\phi = -1$
$\Rightarrow \phi = -\frac{\pi}{4}$ or $\frac{7\pi}{4}$
Now, if instead of cosine, we choose the sine function in the displacement equation, then
x(t) = B sin$(\omega t + \alpha)$
At t = 0, x = 1 cm, $\Rightarrow 1 = B\sin(0 + \alpha)$
or $B\sin\alpha = 1$ ....(iii)
Velocity v(t) = $\frac{dx(t)}{dt} = \frac{d}{dt}[B\sin(\omega t + \alpha)]$
$= +B\omega\cos(\omega t + \alpha)$
Again at t = 0, v(t) = ω cm/s
B cosα = + 1..............(iv)
Squaring and adding Eqs.(iii) and (iv),
$B^2\sin^2\alpha + B^2\cos^2\alpha = (1)^2 + (+1)^2$
$\Rightarrow B^2\sin^2\alpha + B^2\cos^2\alpha = 2$

$B^2\left(\sin^2\alpha+\cos^2\alpha\right)=2$

$B^2 1=2 \Rightarrow B=\pm\sqrt{2}\text{cm}$

Hence, amplitude of the simple harmonic motion in both types of trigonometric wave equation expression = $\sqrt{2}$ cm

Dividing Eq. (iii) by (iv), we get

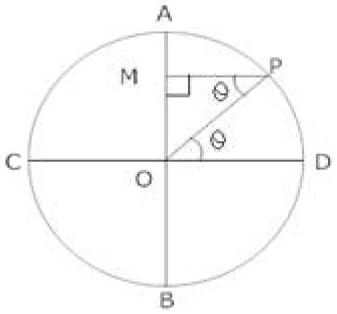
$\frac{B\sin\alpha}{B\cos\alpha}=\frac{1}{1}$ or $\tan\alpha=1$

$\therefore \alpha=\frac{\pi}{4}$, only the phase angle differs for sine and cosine wave equation.

OR

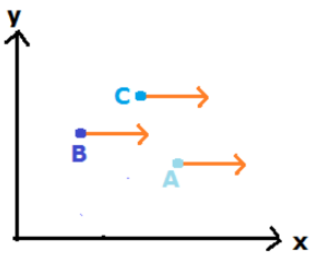
If initially at t = 0 particle was at D

Then at time t Particle is at point P



i. Then draw a perpendicular From P on AB,
   If the displacement OM = Y
   Ratios of circle of reference = Amplitude = a
   then In ΔOMP, ∠POD = ∠OPM = θ ($\because$ Alternate Angles)
   $sin\theta=\frac{OM}{OP}$
   $\Rightarrow \sin\theta=\frac{y}{a}$, 'a' being radius of the above circle.
   $\Rightarrow y=a\sin\theta$
   Again $\theta=\omega t$
   So, $y=a\sin\omega t$
ii. Velocity, $v=\frac{dy}{dt}$
   $\Rightarrow v=\frac{d}{dt}(\text{a}\sin\omega\text{t})$
   $\Rightarrow v=a\omega\cos\omega t$
   again $\cos\theta=\sqrt{1-\sin^2\theta}$
   So, $v=a\omega\times\ \sqrt{1-\sin^2\omega t}$
   From equation of displacement : $\sin\omega t=\frac{y}{a}$
   So, $v=a\omega\times\sqrt{1-\frac{y^2}{a^2}}$
   $\Rightarrow v=aw\sqrt{\frac{a^2-y^2}{a^2}}$
   $v=\omega\sqrt{a^2-y^2}$
iii. Acceleration : $f=\frac{dv}{dt}$
   $\Rightarrow f=a\omega\times\omega(-\sin\omega t)$
   $\Rightarrow f=-\omega^2 a\sin\omega t\Rightarrow f=-\omega^2 y$
iv. $\text{Time Period}, T=\frac{2\pi}{\omega}$
v. $freuency=\frac{1}{\text{T}}=\frac{\omega}{2\pi}$

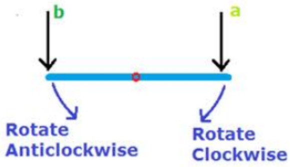
32. A vector has magnitude and direction but in general, it does not have a fixed location of space because a vector can be translated parallel to itself or we can say if a vector is moved parallel to itself keeping its direction and magnitude same then the vector is same or there is no effect on vector as can be shown in figure.



Now here there are three vectors at A, B, C all have the same length so have the same magnitude, have the same direction towards positive x-axis and are thus parallel to each other so all the three vectors are same so there is no effect of location i.e. position is not fixed but in case of position vector position of each point is different and position vector denotes the position in terms of co-ordinates of x and y so position vector has a fixed location and are also directed from the origin so two position vectors cannot be parallel if they are denoting different positions so, position vector has a definite position in space but in general, all vectors does not have a specific position in space

Yes, the vector can certainly vary with time and many vector quantities are just rate of variation of other quantities or vectors can be a function of time for e.g. Velocity of a particle in uniform motion is a function of time and as the time increases the velocity of particle increases or decreases depending upon the acceleration of particle i.e. velocity changes with time likewise in a general vector can vary with time

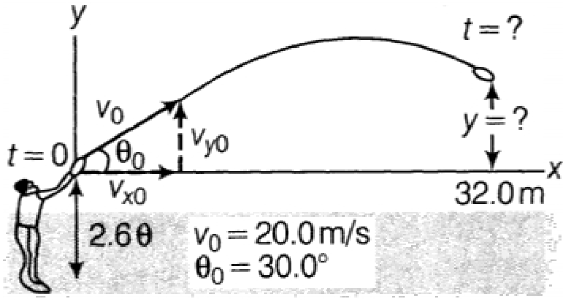
Now we have two equal vectors a and b at different locations in space they necessarily need not have same physical effects though in specific cases they can have some physical effects this is not true always for e.g. two forces of the same magnitude and same direction applied on a body-fixed lever can produce different turning effects as shown in figure



As can be seen, both a and b are directed vertically downwards i.e. the same direction and have the same magnitude so both are equal but turning effect will be different due to them because their location is different in same so we conclude that equal vectors a and b at different locations in space do not necessarily have identical physical effects

OR

To better visualise the solution described here, we first sketch the trajectory as shown in figure.



i. The problem here is to find t when x = 32.0 m. We can use (x = $v_{x_0} t$), if we first find v_{x_0}. From figure, we see that v_{x_0} = v_0 cos θ_0 = (20.0 m/s) (cos 30.0^o)

 = 17.3 m/s

 Using the relation and solve for t.

 x = $v_{x_0} t$

 t = $\frac{x}{v_{x0}}$ = $\frac{32.0\,m}{17.3\,m/s}$ = 1.85 s

ii. We want to find y when x = 32.0 m, or since we have already found the time in part (a), we can state this, find y when t = 1.85 s. Using the relation,

 y = $v_{y_0} t$ - $\frac{1}{2}$gt^2

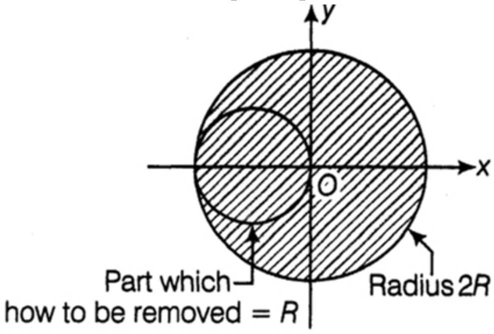
 where v_{y_0} = v_0 sin θ_0 = (20.0 m/s) (sin 30.0^o)

 = 10.0 m/s

 Thus, y = (10.0 m/s)(1.85 s) - $\frac{1}{2}$(9.80 m/s^2)(1.85 s)^2 = 1.73 m

 Since, y = 0 is 2.00 m above the ground, this means the ball is 3.73 m above the ground as it crosses the goal line too much high to be caught at that point.

33. First consider the composite plate,



x-coordinate of centre of mass of composite plate is given by $X_{CM} = \frac{m_1x_1+m_2x_2}{m_1+m_2}$

where,

m_1 = mass of disc of radius 2R

x_1 = position of centre of mass of disc with hole

m_2 = mass of part removed of radius R

x_2 = position of centre of mass of part removed.

Now, as centre of mass of composite plate is at origin,

so

$X_{CM} = 0 = \frac{m_1x_1+m_2x_2}{m_1+m_2}$

or $m_1x_1 + m_2x_2 = 0$

Now, we are finding x_1.

So, $x_1 = -\frac{m_2x_2}{m_1}$

Now, $\frac{m_2}{m_1} = \frac{\text{density} \times \text{ volume of portion 2}}{\text{density} \times \text{ volume of portion 1}}$

$= \frac{\text{thickness} \times \text{ area of portion 2}}{\text{thickness} \times \text{ area of portion 1}}$

$\Rightarrow \frac{m_2}{m_1} = \frac{A_2}{A_1} = \frac{\pi R^2}{\pi(2R)^2 - \pi R^2} = \frac{1}{3}$

Also, x_2 = -R, (negative sign is w.r.t. coordinate axes)

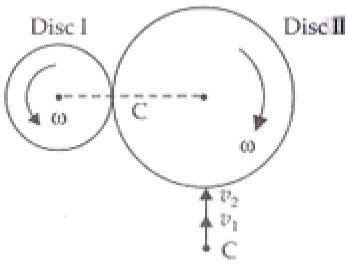
Hence, $x_1 = -\frac{m_2}{m_1} \cdot x_2$

$= -\frac{1}{3}(-R) = \frac{1}{3}R$

So, centre of mass located at ($x = \frac{1}{3}R$, y = 0) Point.

OR

i. $\because v_1 = \omega R$
$v_2 = \omega.2R = 2\omega R$



The direction of $\mathcal{V}_1$ and $\mathcal{V}_2$ at point of contact C are tangentially upward. Frictional force (f) acts due to difference in velocities of disc 1 and, f on 1 due to 2 is f_{12} = upward and f_{21} = downward it will be equal and opposite by Newtons Third Law $f_{12} = -f_{21}$

ii. External forces acting on system are f_{12} and f_{21} which are equal and opposite so net force acting on system $f_{12} = -f_{21}$ or $f_{12} + f_{21} = 0$
$|f_{12}| = |-f_{21}| = F$
$\therefore$ External torque $= F \times 3R$ (anti-clockwise)
As velocity of drum 2 is double i.e., $v_2 = 2v_1$ as in part (a).

iii. Let ω_1 (anti clockwise) and ω_2 (clockwise) are angular velocities of drum 1 and 2 respectively. Finally when their velocities becomes equal no force of friction will act due to no slipping at this stage $v_1 = v_2$ or $\omega_1 R = 2\omega_2 R$ or $\frac{\omega_1}{\omega_2} = \frac{2}{1}$