11th STD.

PUBLIC EXAMINATION MARCH - 2025

Register Number

PART - III

PHYSICS (With Answers)

TIME ALLOWED : 3.00 HOURS] [MAXIMUM MARKS : 70

Instructions :

1) Check the question paper for fairness of printing. If there is any lack of fairness, inform the Hall Supervisor immediately.
2) Use **Blue** or **Black** ink to write and underline and pencil to draw diagrams

PART - I

Note : (i) Answer **all** the questions. **(15 × 1 = 15)**

(ii) Choose the most appropriate answer from the given **four** alternatives and write the option code and the corresponding answer.

1. According to Kepler's Second Law, the radial vector to a Planet from the Sun sweeps out equal areas in equal intervals of time. This law is a consequence of Conservation of ________.
   (a) energy (b) linear momentum
   (c) kinetic energy (d) angular momentum

2. A particle undergoes uniform circular motion. The angular momentum of the particle remains conserved about :
   (a) any point inside the circle
   (b) the centre point of the circle
   (c) any point outside the circle
   (d) the point on the circumference of the circle

3. If the temperature of the wire is increased, then the Young's Modulus will :
   (a) increase rapidly (b) remain the same
   (c) increase by a very small amount
   (d) decrease

4. An athlete covers 5 rounds on a circular track of radius 25 m. The total distance and displacement travelled by him is :
   (a) 785 m, zero (b) 942 m, zero
   (c) 125 m, zero (d) zero, zero

5. A refrigerator has COP of 4. How much work must be supplied to the refrigerator in order to remove 300 J of heat from its interior?
   (a) 600 J (b) 66.67 J (c) 50 J (d) 75 J

6. A pendulum is hung in a very high building, oscillates to and fro motion freely like a simple harmonic oscillator. If the acceleration of the bob is 16 ms^{-2} at a distance of 4m from the mean position, then the time period is :
   (a) 2πs (b) 2s (c) πs (d) 1s

7. The graph between Volume and Temperature in Charles' law is :
   (a) a straight line (b) an ellipse
   (c) a parabola (d) a circle

8. The moment of inertia of a uniform rod about an axis which is perpendicular to the rod and touches any one end of the rod is ________ .
   (a) $I = MR^2$ (b) $I = \frac{1}{12}Ml^2$
   (c) $I = \frac{1}{2}MR^2$ (d) $I = \frac{1}{3}Ml^2$

9. A sample of ideal gas is at equilibrium. Which of the following quantity is zero?
   (a) average velocity (b) rms speed
   (c) most probable speed (d) average speed

10. Which of the following has the dimension of $(\mu_0\varepsilon_0)^{-1/2}$ is :
    (a) Velocity (b) Length
    (c) Force (d) Time

11. Which of the following represents a wave?
    (a) $\frac{1}{(x+vt)}$ (b) $(x - vt)^3$
    (c) $\sin(x + vt)$ (d) $x(x + vt)$

12. An object is dropped in a planet from height 50 m, it reaches the ground in 2 s. The acceleration due to gravity in the planet is :
    (a) $g = 15\ ms^{-2}$ (b) $g = 20\ ms^{-2}$
    (c) $g = 30\ ms^{-2}$ (d) $g = 25\ ms^{-2}$

13. When the object is moving at constant velocity on the rough surface :
    (a) only external force acts on the object
    (b) net force on the object is zero
    (c) only kinetic friction acts on the object
    (d) no force acts on the object

14. Two equal masses m_1 and m_2 are moving along the same straight line with velocities 5 ms^{-1} and –9 ms^{-1} respectively. If the collision is elastic, then calculate the velocities after the collision of m_1 and m_2 respectively.
    (a) –9 ms^{-1} and 5 ms^{-1} (b) –4 ms^{-1} and 10 ms^{-1}
    (c) 5 ms^{-1} and 1 ms^{-1} (d) 10 ms^{-1} and 0 ms^{-1}

15. Which of the following pairs of physical quantities have same dimensions?
    (a) torque and power (b) force and power
    (c) force and torque (d) torque and energy

Part - II

Note: Answer **any six** questions. Question No **24** is **compulsory.** **(6 × 2 = 12)**

16. State Newton's Second Law.
17. What is a PV diagram?
18. Calculate the area of a triangle for which two of its sides are given by the vectors. $\vec{A} = 5\hat{i} - 3\hat{j}$, $\vec{B} = 4\hat{i} + 6\hat{j}$
19. What are the factors affecting the Mean Free Path?
20. Check the dimensional correctness of the given physical equation.
21. Give any two examples of torque in day-to-day life.
22. Explain Resonance. Give an example.
23. Define the Gravitational Field and give its unit.
24. The speed of wave in a certain medium is 900 ms^{-1}. If 3000 waves passes over a certain point of the medium in 2 minutes, then compute its wavelength.

Part - III

Note: Answer **any six** questions. Question No **33** is **compulsory.** **(6 × 3 = 18)**

25. Write the properties of Vector Product. (Any six)
26. Write down the postulates of Kinetic theory of Gases.
27. 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 30^0, find the work done by the force.
28. Write short notes on Geostationary Satellites and Polar Satellites.
29. Explain various modes of heat transfer.
30. Compare the salient features of Static and Kinetic Friction.
31. What is meant by end correction in Resonance Air Column apparatus?
32. What is the relation between Torque and Angular Momentum?
33. A wire 10 m long has a cross-sectional area 1.25×10^{-4} m^2. It is subjected to a load of 5 kg. I Young's Modulus of the material is 4×10^{10} Nm^{-2}, calculate the elongation produced in the wire. (Take $g = 10$ ms^{-2})

Part - IV

Note: Answer **all** the questions. **(5 × 5 = 25)**

34. (a) Explain in detail the various types of errors.

(OR)

(b) Describe Newton's formula for velocity of sound waves in air and explain the Laplace's correction.

35. (a) What is the need for banking of tracks? Explain.

(OR)

(b) State Pascal's law. Explain the working of Hydraulic lift.

36. (a) Derive the expression for Centripetal Acceleration.

(OR)

(b) Explain the heat engine and obtain its efficiency.

37. (a) Describe the horizontal oscillations of a spring.

(OR)

(b) Describe rolling on inclined plane and arrive at the expression for the acceleration.

38. (a) (i) Define Power. Give any two units of Power.
(ii) Calculate the energy consumed in electrical units when a 75 W fan is used for 8 hours daily for one month (30 days). **(OR)**

(b) (i) Derive an expression for energy of satellite.
(ii) Calculate the energy of the Moon orbiting the Earth.

ANSWERS

Part - I

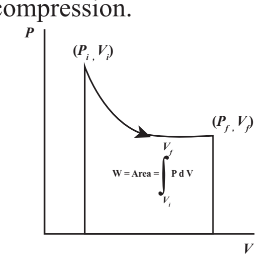
1. (d) angular momentum
2. (b) the center point of the circle
3. (d) decrease
4. (a) 785 m, zero
5. (d) 75 J
6. (c) πs
7. (a) a straight line
8. (d) $I = \frac{1}{3}Ml^2$
9. (a) average velocity
10. (a) Velocity
11. (c) $\sin(x + vt)$
12. (d) $g = 25$ m s^{-2}
13. (b) net force on the object is zero
14. (a) $-9ms^{-1}$ and 5 ms^{-1}
15. (d) torque and energy

Part - II

16. The force acting on an object is equal to the rate of change of its momentum.

$$\vec{F} = \frac{d\vec{p}}{dt}$$

17. PV diagram is a graph between pressure P and volume V of the system. The P-V diagram is used to calculate the amount of work done by the gas during expansion or on the gas during compression.



Pressure P in - Y axis Volume V in - X axis

18. Sides of the triangle $\vec{A} = 5\hat{i} - 3\hat{j}$; $\vec{B} = 4\hat{i} + 6\hat{j}$

Area of the triangle, $A = \frac{1}{2}|\vec{A} \times \vec{B}|$

$$|\vec{A} \times \vec{B}| = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 5 & -3 & 0 \\ 4 & 6 & 0 \end{vmatrix}$$

$$= \hat{i}\,[0 - 0] + \hat{j}\,(0 - 0) + \hat{k}\,(30 + 12) = 42\,\hat{k}$$

$$|\vec{A} \times \vec{B}| = \sqrt{0^2 + 0^2 + 42^2} = \sqrt{42^2} = 42$$

$$\frac{1}{2}|\vec{A} \times \vec{B}| = \frac{1}{2} \times 42 = 21 \text{ square units.}$$

19. (i) Mean free path increases with increasing temperature. As the temperature increases, the average speed of each molecule will increase. It is the reason why the smell of hot sizzling food reaches several meter away than smell of cold food.
(ii) Mean free path increases with decreasing pressure of the gas and diameter of the gas molecules.

20. Let us take the equation of motion v = u + at

Apply dimensional formula on both sides

$[LT^{-1}] = [LT^{-1}] + [LT^{-2}]\,[T]$

$[LT^{-1}] = [LT^{-1}] + [LT^{-1}]$ (Quantities of same dimension only can be added)

We see that the dimensions of both sides are same. Hence the equation is dimensionally correct.

21. (i) The opening and closing of a door about the hinges.
(ii) Turning of a nut using a wrench.
(iii) Opening a bottle cap (or) water top.

22. (i) The frequency of external periodic force (or driving force) matches with the natural frequency of the vibrating body (driven).
(ii) As a result the oscillating body begins to vibrate such that its amplitude increases at each step and ultimately it has a large amplitude.
(iii) Such a phenomenon is known as resonance and the corresponding vibrations are known as resonance vibrations.
(iv) **Example:** The breaking of glass due to sound.

23. The gravitational field intensity $\vec{E}_1$ at a point which is at a distance r from m_1 is defined as the gravitational force experienced by unit mass placed at that point.

$$\vec{E}_1 = -\frac{Gm_1}{r^2}\hat{r}$$

Its unit N / kg (or) ms^{-2}

24. **Solution:**

The speed of a wave in medium v = 900 ms^{-1}
Freqency of wave = no. of waves passing per sec (n) = 3000 waves/2min = $\frac{3000}{2\times 60}$ =25s

Wave length = λ =?

$$v = n\lambda \Rightarrow \lambda = \frac{v}{n}$$

$$\lambda = \frac{900}{25} = 36\text{m} \Rightarrow \lambda = 36\text{m}$$

Part - III

25. **Properties of Vector Products:**

(i) The vector product of any two vectors is always another vector whose direction is perpendicular to the plane containing these two vectors, i.e., orthogonal to both the vectors $\vec{A}$ and $\vec{B}$ even though the vectors $\vec{A}$ and $\vec{B}$ may or may not be mutually orthogonal.

(ii) The vector product of two vectors will have maximum magnitude when sin θ = 1, i.e., θ = 90° i.e., when the vectors $\vec{A}$ and $\vec{B}$ are orthogonal to each other.

$$\left(\vec{A}\times\vec{B}\right)_{max} = AB\hat{n}$$

(iii) The vector product of two non-zero vectors will be minimum when $|\sin\theta| = 0$,
i.e. θ = 0º or 180º.

$$\left[\vec{A}\times\vec{B}\right]_{min} = 0$$

i.e., the vector product of two non–zero vectors vanishes, if the vectors are either parallel or antiparallel.

(iv) The self–cross product, i.e., product of a vector with itself is the null vector

$$\vec{A}\times\vec{A} = AA\sin 0^{\circ}\,\hat{n} = \vec{0}$$

In physics the null vector $\vec{0}$ is simply denoted as zero.

(v) The self–vector products of unit vectors are thus zero.

$$\hat{i}\times\hat{i} = \hat{j}\times\hat{j} = \hat{k}\times\hat{k} = \vec{0}$$

26. (i) All the molecules of a gas are identical, elastic spheres.
(ii) The molecules of different gases are different.
(iii) The number of molecules in a gas is very large and the average separation between them is larger than size of the gas molecules.
(iv) The molecules of a gas are in a state of continuous random motion.
(v) The molecules collide with one another and also with the walls of the container.

27. **Solution :** Force, F = 25 N

Displacement, dr = 15 m

Angle between F and dr, θ = 30º

Work done W = Fdr cosθ

$$W = 25\times 15\times\cos 30^{\circ} = 25\times 15\times\frac{\sqrt{3}}{2}$$

W = 324.76 J

28. **(i) Geostationary Satellite :** It is the satellite which appears at a fixed position and at a definite height to an observer on earth.

(ii) Polar Satellite : It is the satellite which revolves in polar orbit around the earth.

29. **There are three modes of heat transfer:**

Conduction, Convection and Radiation.

(i) Conduction : Conduction is the process of direct transfer of heat through matter due to temperature difference. When two objects are in direct contact with one another, heat will be transferred from the hotter object to the colder one.

The objects which allow heat to travel easily through them are called conductors.

(ii) Convection : Convection is the process in which heat transfer is by actual movement of molecules in fluids such as liquids and gases. In convection, molecules move freely from one place to another. It happens naturally or forcefully Boiling water in a cooking pot is an example of convection.

(iii) Radiation: Radiation is a form of energy transfer from one body to another by electromagnetic waves. Radiation does not require medium to transfer energy from one object to another.

Example:

1. Solar energy from the Sun.
2. Radiation from room heater.

30.

Static friction	Kinetic friction
It opposes the starting of motion	It opposes the relative motion of the object with respect to the surface
Independent of surface area of contact	Independent of surface area of contact
μ_s depends on the nature of materials in mutual contact	μ_k depends on nature of materials and temperature of the surface
Depends on the magnitude of applied force	Independent of magnitude of applied force
It can take values from zero to $\mu_s N$	It can never be zero and always equals to $\mu_k N$ whatever be the speed (true <10 ms^{-1})

31. 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

$$\frac{1}{4}\lambda = L_1 + e$$

Again taking end correction into account, we have

$$\frac{3}{4}\lambda = L_2 + e$$

32. We have the expression for magnitude of angular momentum of a rigid body as, L=Iω. The expression for magnitude of torque on a rigid body is, τ = Iα.

We can further write the expression for torque as,

$$\tau = I\frac{d\omega}{dt} \because \left(\propto = \frac{d\omega}{dt}\right) \quad ...(1)$$

Where, ω is angular velocity and ∝ is angular acceleration. We can also write equation (1) as.

$$\tau = \frac{d(I\omega)}{dt}; \quad \tau = \frac{dL}{dt}$$

33. **Solution :**

We know that $\frac{F}{A} = Y \times \frac{\Delta L}{L}$

$$\Delta L = \left(\frac{F}{A}\right)\left(\frac{L}{Y}\right) = \left(\frac{50}{1.25\times10^{-4}}\right)\left(\frac{10}{4\times10^{10}}\right) = 10^{-4}\text{m}$$

Part - IV

34. **(a) Types of errors :** (a) Systematic error (b) Random error (c) Gross error

(a) Systematic errors : They are reproducible inaccuracies that are consistently in the same direction.

It is classified as follows :

(1) Instrumental errors : It arises when an instrument is not calibrated properly at the time of manufacturing. It can be corrected by choosing accurate instruments.

(2) Imperfections in experimental technique or procedure: It is due to the limitations in the experimental arrangement. To overcome this, necessary and proper correction is 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.

(b) Random error :

(1) It arises due to random and unpredictable variations in experimental conditions like pressure, temperature, voltage supply, etc.

(2) It also arises due to personal errors by the observer. It is sometimes called 'chance errors'.

(3) It can be minimised by repeating the observations a large number of times and taking the arithmetic mean of all the observations.

(c) Gross error :

(1) The error caused due to the shear carelessness of an observer is called gross error.

(2) It can be minimized only when an observer is careful and mentally alert.

(OR)

(b) 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

$$PV = \text{Constant} \quad \text{..... (1)}$$

Differentiating equation (1), we get

$$PdV + VdP = 0$$

or, $$P = -V\frac{dP}{dV} = K_I \quad \text{..... (2)}$$

where, K_I is an isothermal bulk modulus of air. Substituting equation (2) in equation $v = \sqrt{\frac{K}{\rho}}$, the speed of sound in air is

$$v_T = \sqrt{\frac{K_I}{\rho}} = \sqrt{\frac{P}{\rho}} \quad \text{..... (3)}$$

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

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

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

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

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

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

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 Correction : Laplace assumed 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

$$PV^\gamma = \text{constant} \quad \text{..... (4)}$$

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 (4) on both the sides, we get

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

or, $$\gamma P = -V\frac{dP}{dV} = K_A \quad \text{..... (5)}$$

where, K_A is the adiabatic bulk modulus of air. Now, substituting equation (5) in equation $v = \sqrt{\frac{K}{\rho}}$, the speed of sound in air is

$$v_A = \sqrt{\frac{K_A}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\gamma}\, v_T \quad \text{..... (6)}$$

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

35. **(a)** (i) In a leveled circular road, skidding mainly depends on the coefficient of static friction μ_s. The coefficient of static friction depends on the nature of the surface which has a maximum limiting value.

(ii) To avoid this problem, usually the outer edge of the road is slightly raised compared to inner edge.

(iii) This is called banking of roads or tracks. This introduces an inclination, and the angle is called banking angle.

(iv) Let the surface of the road make angle θ with horizontal surface. Then the normal force makes the same angle θ with the vertical.

(v) When the car takes a turn, there are two forces acting on the car:
 (a) Gravitational force mg (downwards)
 (b) Normal force N (perpendicular to surface)

(vi) We can resolve the normal force into two components. N cos θ and N sin θ.

(vii) The component N cos θ balances the downward gravitational force 'mg' and component N sin θ will provide the necessary centripetal acceleration. By using Newton second law.

$$N\cos\theta = mg$$

$$N\sin\theta = \frac{mv^2}{r}$$

By dividing the equations we get $\tan\theta = \frac{v^2}{rg}$

$$v = \sqrt{rg\tan\theta}$$

Need Banking of Tracks

(i) The banking angle θ and radius of curvature of the road or track determines the safe speed of the car at the turning.

(ii) If the speed of car exceeds this safe speed, then it starts to skid outward but frictional force comes into effect and provides an additional centripetal force to prevent the outward skidding.

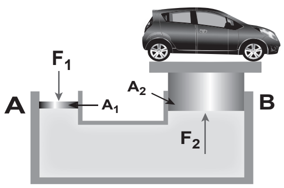
(iii) At the same time, if the speed of the car is little lesser than safe speed, it starts to skid inward and frictional force comes into effect, which reduces centripetal force to prevent inward skidding.

(iv) However if the speed of the vehicle is sufficiently greater than the correct speed, then frictional force cannot stop the car from skidding.

(OR)

(b) Pascal's law states that if the pressure in a liquid is changed at a particular point, the change is transmitted to the entire liquid without being diminished in magnitude.

Application of Pascal's law:



Hydraulic lift

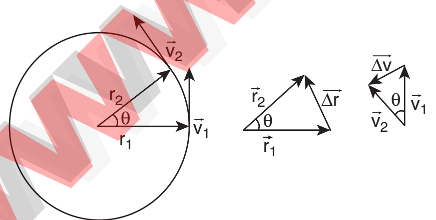
Hydraulic lift: Hydraulic lift which is used to lift a heavy load with a small force. It is a force multiplier. It consists of two cylinders A and B connected to each other by a horizontal pipe, filled with a liquid. They are fitted with frictionless pistons of cross-sectional areas A_1 and A_2 ($A_2 > A_1$). Suppose a downward force F is applied on the smaller piston, the pressure of the liquid under this piston increases to P $\left(\text{where, } P = \dfrac{F_1}{A_1}\right)$.

According to Pascal's law, this increased pressure P is transmitted undiminished in all directions. Therefore a pressure is exerted on piston B. Upward force on piston B is

$$F_2 = P \times A_2 = \frac{F_1}{A_1} \times A_2 \Rightarrow F_2 = \frac{A_2}{A_1} \times F_1$$

Therefore by changing the force on the smaller piston A, the force on the piston B has been increased by the factor $\dfrac{A_2}{A_1}$ and this factor is called the mechanical advantage of the lift.

36. **(a)** (i) Consider the position vectors and velocity vectors shift through the some angle θ in a small interval of time Δt as shown in Figure



(ii) In uniform circular motion,

$$r = |\vec{r}_1| = |\vec{r}_2| \quad \text{and} \quad v = |\vec{v}_1| = |\vec{v}_2|$$

(iii) From Figure, the geometrical relationship between the magnitude of position and velocity vectors is given by,

$$\frac{\Delta r}{r} = -\frac{\Delta v}{v} = \theta$$

(iv) Here the negative sign implies that Δv points radially inward, towards the center of the circle.

$$\Delta v = -v\left(\frac{\Delta r}{r}\right)$$

(v) Dividing both sides by Δt, we get,

$$a = \frac{\Delta v}{\Delta t} = -\frac{v}{r}\left(\frac{\Delta r}{\Delta t}\right)$$

(vi) Applying the limit $\Delta t \to 0$, We get,

$$\frac{dv}{dt} = -\frac{v}{r}\left(\frac{dr}{dt}\right)$$

(vii) Since $a_c = \dfrac{dv}{dt}$ and $v = \dfrac{dr}{dt}$, we can write,

$$\boxed{a_c = -\frac{v^2}{r}} = \frac{v^2}{r} \quad v = \omega r$$

where a_c is the centripetal acceleration.

$$\boxed{a = -\omega^2 r}$$

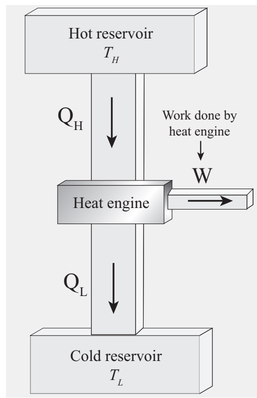
(OR)

(b) Heat engine is a device which takes heat as input and converts this heat into work by undergoing a cyclic process.

A heat engine has three parts:

(a) Hot reservoir (b) Working substance
(c) Cold reservoir

A Schematic diagram for heat engine is given below in the Figure (a).



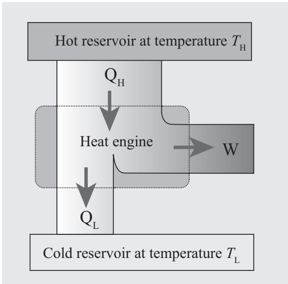
(a) Heat Engine

1. **Hot reservoir (or) Source:** It supplies heat to the engine. It is always maintained at a high temperature T_H
2. **Working substance:** It is a substance like gas or water, which converts the heat supplied into work.
3. **Cold reservoir (or) Sink:** The heat engine ejects some amount of heat (Q_L) in to cold reservoir after it doing work. It is always maintained at a low temperature T_L.

The heat engine works in a cyclic process. After a cyclic process it returns to the same state. Since the heat engine returns to the same state after it ejects heat, the change in the internal energy of the heat engine is zero.

The efficiency of the heat engine is defined as the ratio of the work done (output) to the heat absorbed (input) in one cylic process.

Let the working substance absorb heat Q_H units from the source and reject Q_L units to the sink after doing work W units as shown in the Figure (b).



(b) Heat engine

We can write

Input heat = Work done + ejected heat

$Q_H = W + Q_L$

$W = Q_H - Q_L$

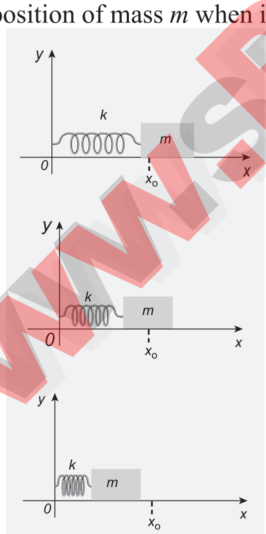
Then the efficiency of heat engine

$$\eta = \frac{\text{output}}{\text{input}} = \frac{W}{Q_H} = \frac{Q_H - Q_L}{Q_H} \Rightarrow \eta = \frac{\text{output}}{\text{input}} = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

Note that Q_H, Q_L and W all are taken as positive, a sign convention followed in this expression.

Since $Q_L < Q_H$, the efficiency (η) always less than 1. This implies that heat absorbed is not completely converted into work.

37. (a) (i) Consider a system containing a block of mass m attached to a massless spring with stiffness constant or force constant or spring constant k placed on a smooth horizontal surface (frictionless surface) as shown in Figure Let x_0 be the equilibrium position or mean position of mass m when it is left undisturbed.



Horizontal oscillation of a spring-mass system

(ii) Let F be the restoring force (due to stretching of the spring) which is proportional to the amount of displacement of block. For one dimensional motion, mathematically, we have

$F = \propto x \quad \Rightarrow \quad F = -kx$

(iii) Where negative sign implies that the restoring force will always act opposite to the direction of the displacement. This equation is called Hooke's law.

(iv) This is not always true; in case if we apply a very large stretching force, then the amplitude of oscillations becomes very large (which means, force is proportional to displacement containing higher powers of x) and therefore, the oscillation of the system is not linear and hence, it is called non-linear oscillation.

(v) From Newton's second law, we can write the equation for the particle executing simple harmonic motion

$$m\frac{d^2x}{dt^2} = -kx \quad \Rightarrow \quad \frac{d^2x}{dt^2} = -\frac{k}{m}x \qquad ...(1)$$

Comparing the equation (1) with simple harmonic motion equation, we get

$$\omega^2 = \frac{k}{m}$$

which means the angular frequency or natural frequency of the oscillator is

$$\omega = \sqrt{\frac{k}{m}} \text{ rad } s^{-1} \qquad ...(2)$$

The frequency of the oscillation is

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{k}{m}} \text{ Hertz .} \qquad ..(3)$$

and the time period of the oscillation is

$$T = \frac{1}{f} = 2\pi\sqrt{\frac{m}{k}} \text{ seconds}$$

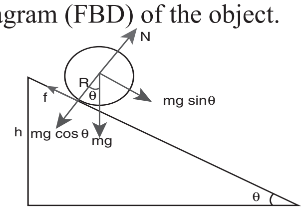
(OR)

(b) Acceleration of the rolling object:

(i) Let us assume a round object of mass m and radius R is rolling down an inclined plane without slipping as shown in Figure.

(ii) There are two forces acting on the object along the inclined plane. One is the component of gravitational force (mg sinθ) and the other is the static frictional force (f).

(iii) The other component of gravitation force (mg cosθ) is cancelled by the normal force (N) exerted by the plane. As the motion is happening along the incline, we shall write the equation for motion from the free body diagram (FBD) of the object.



Rolling on inclined plane

(iv) For translational motion, mg sinθ is the supporting force and f is the opposing force,

$$mg\sin\theta - f = ma \qquad ...(1)$$

(v) Then mg sinθ cannot cause torque as it passes through it but the frictional force f can set torque of Rf. $Rf = I\alpha$

(vi) By using the relation, $a = r\alpha$, and moment of inertia $I = mK^2$, we get,

$$Rf = mK^2 \frac{a}{R} \; ; \; f = ma\left(\frac{K^2}{R^2}\right)$$

(vii) Now equation (1) becomes,

$$mg\sin\theta - ma\left(\frac{K^2}{R^2}\right) = ma$$

$$mg\sin\theta = ma + ma\left(\frac{K^2}{R^2}\right)$$

$$a\left(1+\frac{K^2}{R^2}\right) = g\sin\theta$$

(viii) After rewriting it for acceleration, we get,

$$a = \frac{g\sin\theta}{\left(1+\frac{K^2}{R^2}\right)} \quad ...(2)$$

(ix) We can also find the expression for final velocity of the rolling object by using third equation of motion for the inclined plane. $v^2 = u^2 + 2as$.

(x) When h is the vertical height of the incline, the length of the incline s is, $s = \frac{h}{\sin\theta}$

$$v^2 = 2\frac{g\sin\theta}{\left(1+\frac{K^2}{R^2}\right)}\left(\frac{h}{\sin\theta}\right) = \frac{2gh}{\left(1+\frac{K^2}{R^2}\right)}$$

(xi) By taking square root,

$$v = \sqrt{\frac{2gh}{\left(1+\frac{K^2}{R^2}\right)}} \quad ...(3)$$

(xii) The time taken for rolling down the incline could also be written from first equation of motion as, $v = u + at$. Then,

$$t = \frac{v}{a}$$

$$t = \left(\sqrt{\frac{2gh}{\left(1+\frac{K^2}{R^2}\right)}}\right)\left(\frac{\left(1+\frac{K^2}{R^2}\right)}{g\sin\theta}\right) = \sqrt{\frac{2h\left(1+\frac{K^2}{R^2}\right)}{g\sin^2\theta}} \quad ...(4)$$

(xiii) The equation suggests that for a given incline, the object with the least value of radius of gyration K will reach the bottom of the incline first.

38. **(a) (i) Power :**

Definition of power : 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.

$$\text{Power}(P)\frac{\text{work done}(W)}{\text{time taken}(t)} \Rightarrow P = \frac{W}{t}$$

Unit of power : The higher units are kilowatt(kW), megawatt(MW), and Gigawatt(GW).

(ii) Solution : Given : P = 75 W

$t = 8 \times (30 \text{ days}) = 240\text{h}$

$E = P \times t = 75 \times 240 = 18000 \text{ Wh} = 18 \text{ kwh}$

1unit = 1 kwh

E = 18 units.

(OR)

(b) (i) Energy of an Orbiting Satellite : The total energy of a satellite orbiting the Earth at a distance h from the surface of Earth is calculated as follows; The total energy of the satellite is the sum of its kinetic energy and the gravitational potential energy. The potential energy of the satellite is,

$$U = -\frac{GM_sM_E}{(R_E + h)}$$

Here M_s - mass of the satellite, M_E - mass of the Earth, R_E - radius of the Earth.

The kinetic energy of the satellite is

$$K.E = \frac{1}{2}M_s v^2 \quad ...(1)$$

Here v is the orbital speed of the satellite and is equal to

$$v = \sqrt{\frac{GM_E}{(R_E + h)}}$$

Substituting the value of v in (1), the kinetic energy of the satellite becomes,

$$K.E = \frac{1}{2}\frac{GM_EM_s}{(R_E + h)}$$

Therefore the total energy of the satellite is

$$E = \frac{1}{2}\frac{GM_EM_s}{(R_E + h)} - \frac{GM_sM_E}{(R_E + h)} = -\frac{GM_sM_E}{2(R_E + h)}$$

The negative sign in the total energy implies that the satellite is bound to the Earth and it cannot escape from the Earth.

(ii) Solution : Assuming the orbit of the Moon to be circular, the energy of Moon is given by,

$$E_m \frac{GM_EM_E}{2R_M}$$

where M_E is the mass of Earth 6.02×10^{24} kg; M_m is the mass of Moon 7.35×10^{22} kg; and R_m is the distance between the Moon and the center of the Earth 3.84×10^5km

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

$$E_m = -\frac{6.67\times10^{-11}\times6.02\times10^{24}\times7.35\times10^{22}}{2\times3.84\times10^5\times10^3}$$

$E_m = -38.42 \times 10^{-19} \times 10^{46}$

$E_m = -38.42 \times 10^{27}$ joule

The negative energy implies that the Moon is bound to the Earth.

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