PHYSICS CLASS XI

CHAPTER – 7 SYSTEM OF PARTICLES AND ROTATIONAL MOTION

Q.1. If a cube is melted and is casted into a sphere, does moment of inertia about an axis through centre of mass increases or decreases.

Ans. Moment of inertia of a sphere is less than of a cube of same mass.

Q.2. What happens to the moment of force about a point, if the line of action of the force moves towards the point?

Ans. Moment of force = force × the perpendicular distance of the line of action of force from the axis of rotation.

Hence, the moment of force about a point decrease if the line of action of the force moves towards that point.

Q.3. Why a wrench of longer arm is preferred in comparison to a wrench of shorter arm?

Ans. The torque applied on the nut by the wrench is equal to the force multiplied by the perpendicular distance from the axis of rotation. Hence, to increase torque a wrench of longer arm is preferred.

Q.4. Why in hand driven grinding machine, handle is put near the circumference of the stone or wheel?

Ans. For a given force, torque can be increased if the perpendicular distance of the point of application of the force from the axis of rotation is increased.

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Hence, the handle put near the circumference produces maximum torque.

Q.5. When is a body lying in a gravitation field in stable equilibrium ?

Ans. A body in a gravitation field will be in stable equilibrium, if the vertical line through its centre of gravity passes through the base of the body.

Q.6. Why is moment of inertia also called rotational inertia?

Ans. The moment of inertia gives a measure of inertia in rotational motion. So, it is called rotational inertia.

Q.7. Does the moment of inertia of a rigid body change with the speed of rotation?

Ans. No because the moment of inertia depends upon the axis of rotation and distribution of mass.

Q.8. Can the mass of body be taken to be concentrated at its centre of mass for the purpose of calculating its rotational inertia?

Ans. No, the moment of inertia greatly depends on the distribution of mass about the axis of rotation.

Q.9. About which axis would a uniform cube have a minimum rotational inertia?

Ans. In a uniform cube, the mass is more concentrated about a diagonal.

Q.10. If net torque on a rigid body is zero, does it linear momentum necessary remain conserved?

Ans. The linear momentum remain conserved if the net force on the system is zero.

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Q.11. Explain how a cat is able to land on its feet after a fall taking the advantage of principle of conservation of angular momentum?

Ans. When a cat falls to ground from a height, it stretches its body alongwith the tail so that its moment of inertia becomes high. Since, $I\omega$ is to remain constant, the value of angular speed ω decreases and therefore the cat is able to land on the ground gently.

Q.12. The speed of a whirl wind in a tornado is alarmingly high. Why?

Ans. In a whirl wind, the air from nearby region gets concentrated in a small space thereby decreasing the value of moment of inertia considerably Since, $I\omega$ = constant, due to decrease in moment of inertia, the angular speed becomes quite high.

Q.13. If earth contracts to half its radius. What would be the length of the day?

Ans. The moment of inertia $\left(I = \frac{2}{5}MR^2\right)$ of the earth about its own axis will become one – fourth and so its angular velocity will become four times (L = $I\omega$ = constant). Hence, the time period will reduce to one-fourth (T = $2\pi/\omega$), i.e., 6 hours.

Q.14. Two boys of the some weight sit at the opposite ends of a diameter of a rotating circular table. What happens to the speed of rotation if they move nearer to the axis of rotation?

Ans. The moment of inertia of the system (circular table + two boys) decreases. To conserve angular momentum (L = $I\omega$ = constant), the speed of rotation of the circular table increases.

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Q.15. A person is standing on a rotating table with metal spheres in his hands. If he withdraw his hands to his chest, what will be the effect on his angular velocity?

Ans. When the person withdraws his hands to his chest, his moment of inertia decreases. No external torque is acting on the system. So, to conserve angular momentum, the angular velocity increases.

Q.16. Why does a solid sphere have smaller moment of inertia than a hollow cylinder of same mass and radius about an axis passing through their axis of symmetry.

Ans. All mass of a hollow cylinder lies at a distance R from axis of rotation. Whereas in case of a sphere, most of mass lies at a distance less than R from axis of rotation.

As moment of inertia is $\Sigma M_i R_i^2$, so sphere as a lower value of moment of inertia.

Q.17. A solid cylinder of mass 20 kg rotates about its axis with angular speed of 100 rad/s. The radius of cylinder is 0.25 m. What is KE of rotation of cylinder.

Ans. M = 20 kg, ω = 100 rad/s, R = 0.25 m

Moment of inertia of cylinder about its own axis = $\frac{1}{2}$ MR^2

$$= \frac{1}{2} \times 20 \times (0.25)^2 = 0.625 \text{ kg} - \text{m}^2$$

Rotational KE = $\frac{1}{2} I\omega^2$

$$= \frac{1}{2} \times 0.625 \times (100)^2 = 3125\text{J}$$

Q.18. If ice on poles melts, then what is change in duration of day?

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Ans. Molten ice from poles goes into ocean and so mass is going away from axis of rotation. So, moment of inertia of earth increase and to conserve angular momentum, angular velocity (ω) decrease. So, time period of rotation increase (T = $2\pi/\omega$) So, net effect of global warming is increased in duration of day.

Q.19. A solid cylinder of mass 20 kg rotates about its axis with angular speed (100 rad/s). The radius of cylinder is 0.25 m. What is the kinetic energy associated with the rotation of the cylinder? What is the magnitude of angular momentum of the cylinder about its axis?

Ans. Moment of inertia of cylinder about its axis = $\frac{1}{2}MR^2$,

M = mass, R = radius

$$= \frac{1}{2} \times 20 \times (0.25)^2 kg - m^2$$

$$= 0.625 \text{ kg} - \text{m}^2$$

Kinetic energy of rotating cylinder

$$= \frac{1}{2} I\omega^2 = \frac{1}{2}(0.625)(100)^2 \text{ J}$$

$$= 3125 \text{ J}$$

Angular momentum of cylinder about its own axis

$$= I\omega = 0.625 \times 100$$

$$= 62.5 \text{ kg-m}^2/\text{s}$$

Q.20. A rope of negligible mass is would round a hollow cylinder of mass 3 kg and radius 40 cm. What is angular acceleration of the cylinder, if the rope is

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pulled with a force of 30 N? What is linear acceleration of the rope? Assume no slipping.

Ans. Torque on cylinder, τ = force × radius

= 30 × 0.4 = 12 N – m

Moment of inertia of hollow cylinder about its axis

I = MR^2 = 3 × $(0.4)^2$

= 0.48 kg – m^2

Also, $\tau = I\alpha$

⇒ $\alpha = \frac{\tau}{I}$

∴ $\alpha = \frac{12}{0.48}$ = 25 s^{-2}

Linear acceleration of rope

a = $\frac{F}{m} = \frac{30}{3}$ = 10 m/s^2

Q.21. A hoop of radius 2 m weighs 100 kg. It rolls along a horizontal floor so that its centre of mass has a speed of 20 cm/s. How much work has to be done to stop it?

Ans. Moment of inertia of hoop about its centre

I = MR^2

and energy of loop

= translational kinetic energy of CM and rotational kinetic energy about axis through CM.

$= \frac{1}{2}mv_{CM}^2 + \frac{1}{2}I\omega^2 \left(I = mR^2 and\ \omega = \frac{v}{R}\right)$

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$= \frac{1}{2}mv_{CM}^2 + \frac{1}{2}mR^2 \times \frac{v^2CM}{R^2} = mv_{CM}^2$

Work done is stopping the hoop

= total KE of loop

$= mv_{CM}^2$ = 100 × $(0.2)^2$ = 4J

Q.22. A wheel in uniform motion about an axis passing through its centre and perpendicular top its plane is considered to be in mechanical (translation and rotational) equilibrium because no net external torque is required to sustain its motion.

However, the particles that constitute the wheel do experience a centripetal acceleration towards the centre. How do you reconcile this fact with the wheel begin in equilibrium?

How would you set a half wheel into uniform motion about an axis passing through the centre of mass of the wheel and perpendicular to its plane? Will you require external forces to sustain the motion?

Ans. The centripetal acceleration in a wheel arise due to the internal elastic forces which in pairs cancel each other. So the system remains in equilibrium during rolling.

In a half wheel the system is not symmetrical so, direction of angular momentum does not coincide with the direction of angular velocity and hence an external torque is required to maintain the rotation.

Q.23. A bullet of mass 10 g and speed 500 m/s is fired into a door and gets embedded exactly at the centre of the door. The door is 1.0 m wide and weight

12 kg. It is hinged at one end and rotates about a vertical axis practically without friction. Find the angular speed of the door just after the bullet embeds into it.

Ans. Given, mass of bullet (m) = 10g = 0.01 kg

Speed of bullet (v) = 500 m/s

Width of the door (l) = 1.0 m

Mass of the door (M) = 12 kg

As bullet gets embedded exactly at the centre of the door, therefore its distance from the hinged end of the door,

$$(r) = \frac{l}{2} = \frac{I}{2} m$$

Angular momentum transferred by the bullet to the door,

$$(L) = mv \times r = 0.01 \times 500 \times \frac{1}{2} = 2.5 \text{ J-s}$$

Moment of inertia of the door about the vertical axis at one of its end, (I) = $\frac{Ml^2}{3}$ = $\frac{12\times(I)^2}{3}$ = 4 kg – m^2

But angular momentum, L = $I\omega$

$$2.5 = 4 \times \omega$$

$$\omega = \frac{2.5}{4} = 0.625 \text{ rad/s}$$

Q.24. A cylinder of mass 10 kg and radius 15 cm is rolling perfectly on a plane of inclination 30°. The coefficient of static friction, μ_s = 0.25.

(i) How much is the force of friction acting on the cylinder?

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(ii) What is the work done against friction during rolling?

(iii) If the inclination θ of the plane is increased, at what value of θ does the cylinder begin to skid and not roll perfectly?

Ans. Given, mass of the cylinder m = 10 kg

Radius r = 15 cm = 0.5 m

Coefficient of static friction μ_s = 0.25

(i) Force of friction acting on the cylinder on the inclined plane, F = $\frac{1}{3}$ mg

$\sin\theta = \frac{1}{3} \times 10 \times 9.8 \times \sin 30°$

$= \frac{1}{3} \times 10 \times 9.8 \times \frac{1}{2} = 16.3$ N

(ii) Force of friction acts perpendicular to the direction of displacement.

∴ Work done against friction during rolling

$W = F_s \cos 90° = 0$

(iii) For rolling without slipping,

$\mu = \frac{1}{3} \tan\theta$

or $\tan\theta = 3\mu = 3 \times 0.25 = 0.75 = \tan 36° 54'$

or $\theta = 36° 54' = 37°$

Q.25. It was summer season and Ishant was sleeping at top of roof when heard some noise at downstairs when he looked down, he saw that two robbers were holding his brother at gun point, suddenly he saw a big drum near to him and he rolled the drum from the stairs which hit one of the robber who was holding

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gun and robber fell down. In mean time other one run away and the family caught that robber and handed him over to the police.

(i) What values of Ishant saved his brother's life?

(ii) What kind of motion is described by the drum?

(iii) If a thin hollow cylinder, opened at both the ends and weighing 5 kg rolls with a speed of 10m/s without slipping. What is the kinetic energy of cylinder?

(iv) What is meant by rolling without slipping ?

Ans. (i) Mental alertness, bravery, presence of mind and quick decision.

(ii) Rolling motion i.e., (Rotation + Translation)

(iii) Given, m = 5 kg, v = 10 m/s

As cylinder rolls without slipping so it has translational and rotational KE.

$\therefore \quad KE = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

As $\quad I = mr^2$ and $v = r\omega$

So $\quad KE = \frac{1}{2}mv^2 + \frac{1}{2}(mr^2)\omega^2 = \frac{1}{2}mv^2 + \frac{1}{2}mv^2$

$= mv^2 = 5 \times 10^2 = 500$ J

(iv If an object rolls across a surface in such a way that there is no relative motion of object and surface at point of contact, then the motion is called rolling without slipping.

or $\quad h = \frac{3}{4}\frac{v^2}{g} = \frac{3}{4} \times \frac{5^2}{9.8} = 1.91$ m

In ΔABC, $\quad AB = \frac{h}{\sin 30°}$

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or AB = $\frac{1.91}{0.5}$ = 3.82 m

So, cylinder rolls a direction of 3.82 m up the incline.

Q.26. A man stand on a rotating platform with his arms stretched horizontally holding a 5 kg weight in each hand. The angular speed of the platform is 30 rpm. The man then brings his arms close to his body with the distance of each weight from the axis changing from 90 cm to 20 cm. The moment of inertia of the man together with the platform may be taken to be constant and equal to 7.6 kg – m^2.

(i) What is his new angular speed? (Neglect friction)

(ii) Is kinetic energy conserved in the process? If not, from where does the change come about?

Ans. (i) Moment of inertia of man and platform system

I_i = 7.6 – m^2

Change in moment of inertia of man and platform system when he stretches his hands to a distance of 90 cm = 2 × mr^2 = 2 × 5 × $(0.9)^2$

= 8.1 kg – m^2

I_i = I + 8.1 = 7.6 + 8.1 = 15.7 kg – m^2

Initial angular velocity ω_i = 30 rpm

Initial angular momentum of system

$L_i = I_i\omega_i$ = 15.7 kg - m^2 × 30 rpm

When man folds his hands to a distance of 20 cm

Moment of inertia of man = 2 × mr^2 = 2 × 5 × $(0.2)^2$

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$= 0.4 \text{ kg} - \text{m}^2$

So, final moment of inertia of man and platform system

$= 7.6 + 0.4 = 8 \text{ kg} - \text{m}^2$

Final angular momentum of system

$$L_f = I_f \omega_f = 8 \times \omega_f$$

Equating initial and final values

$$L_i = L_f$$

$\Rightarrow \quad \omega_f = \frac{15.7 \times 30}{8}$

$= 58.88$ rpm

(ii) KE is not conserved in process.

$$K_{final} > K_{initial}$$

Muscular work done by the man in folding his arms is converted into KE.

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