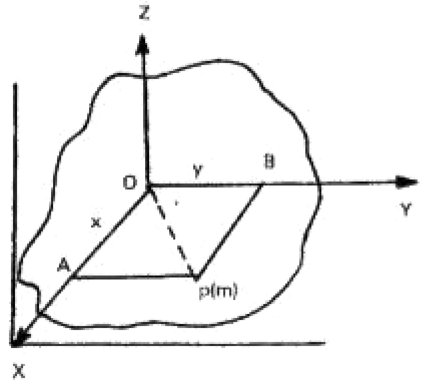
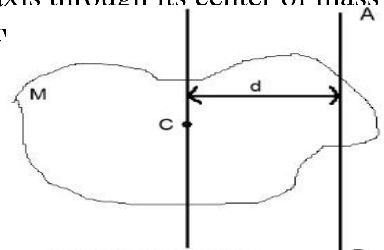
Applied Physics - I (Unit - 4 : Rotational Motion)			
Sl. No.	**Question**	**Taxonomy Level**	**Mark**
1	**Define Torque.**	**Remembering**	**2**
ANS	Torque may be defined as the force that causes an object to rotate around an axis. It is also called the moment of force. It is given as the product of force and the perpendicular distance of force from the axis of rotation i.e. Torque $\vec{\tau} = \vec{r} \times \vec{F}$		**1** **1**
2	**Define angular momentum.**	**Remembering**	**2**
ANS	a. Angular momentum is a vector quantity that describes the rotational motion of an object or system. It is the rotational equivalent of linear momentum. b. It is given as the product of linear momentum and the perpendicular distance of the linear momentum from the axis of rotation. In vector form, $\vec{L} = \vec{r} \times \vec{p}$		**1** **1**
3	**State principle of conservation of angular momentum**	**Remembering**	**2**
ANS	a. The principle of conservation of angular momentum is defined as, "if net external torque on the body is zero, then the total angular momentum of the body remains constant." b. Mathematically, if $\vec{\tau}_{net} = 0$ then $\frac{d\vec{L}}{dt} = 0$ Thus L= $I\omega$ = constant		**1** **1**
4	**Define moment of Inertia.**	**Remembering**	**2**
ANS	a. Moment of Inertia is a measure of the rotational inertia of a body, i.e., the opposition that the body exhibits to having its speed of rotation about an axis altered by the application of a torque. b. It is given as the product of mass of the particle and the square of the distance of the particle from the axis of rotation. i.e. $I = mr^2$		**1** **1**
5	**State the factors on which moment of inertia of a body depends.**	**Understanding**	**2**
ANS	Factors on which M.I depends on are i. The distribution of mass of the body about the axis of rotation ii. Distribution of the body from the axis of rotation iii. Shape of the body iv. Orientation & position of the axis of rotation w.r.t. the body		**0.5** **0.5** **0.5** **0.5**

6	**What is the real world significance of moments of inertia?**	**Understanding**	**2**
ANS	a. Moment of inertia is crucial in real-world applications because it determines how easily an object can be rotated, essentially measuring its resistance to angular acceleration. b. It is vital for designing machines and structures where rotational motion is involved, like car flywheels, spinning turbines, aircraft, and even the stability of ships, allowing engineers to optimize their design based on desired rotational behavior by manipulating the distribution of mass within the object.		**1** **1**
7	**Write two applications of conservation of angular momentum.**	**Understanding**	**2**
ANS	a. The angular momentum of planets remains conserved when the planets revolve around the sun. b. Ice skaters use conservation of angular momentum to change angular velocity by changing its moment of inertia.		**1** **1**
8	**The angular speed of a planet increases when its position in the orbit is near to the sun. Explain why?**	**Understanding**	**2**
ANS	When a planet revolving around the sun in an elliptical orbit comes near the sun, its angular speed increases. This is because the planet comes near the sun, its m.I decreases & hence according to the law of conservation of angular momentum ($I\omega = const$), Its angular velocity increases.		**2**
9	**Derive the relation between angular momentum and moment of inertia for a mass m rotated about axis of rotation in circle of radius r.**	**Understanding**	**2**
ANS	a. A particle of mass m rotated about axis of rotation in circle of radius r then angular momentum L= rp = mvr = $mr^2\omega$ (linear momentum p=mv, v=rω) b. Again, I=Moment of Inertia of the particle = mr^2 Therefore, $L=mr^2\omega= I\omega$		**1** **1**
10	**Define Rotational Motion with examples**	**Remembering & Understanding**	**2**
ANS	a. A rigid body has rotational motion if it rotates about a fixed axis such that every particle of the body moves in a circle with its centre of axis of rotation. b. The examples of rotational motion are motion of the wheel, gears, motors, etc. The motion of the blades of the helicopter is also rotatory motion. A door, swiveling on its hinges as we open or close it.		**1** **1**
11	**The moment of Inertia of a ring about an axis passes through its center and perpendicular to its plane is MR^2. Find the moment of inertia about its diameter.**	**Applying**	**2**
ANS	a. The Perpendicular Axis Theorem states that for a planar object, the moment of inertia about an axis perpendicular to the plane (I_{ZZ}) is equal to the sum of the moments of inertia about two perpendicular axes in the plane of the object (I_{XX} and I_{YY}). Mathematically, $I_{ZZ} = I_{XX} + I_{YY}$ b. The moment of Inertia of a ring about an axis passes through its center and perpendicular to its plane is given as $I_{ZZ}=MR^2$.		**1** **1**

	Now, $I_{XX}=I_{YY}=I_{ZZ}/2=(1/2)\ MR^2$ The moment of Inertia of a ring about its diameter is $(1/2)\ MR^2$		
12	**The moment of inertia of a body is $5kgm^2$. Calculate the amount of torque required for producing angular acceleration of $2rads^{-2}$.**	**Applying**	**2**
ANS	Torque $(\tau)=I \times \alpha = 5kg\ m^2 \times 2rad\ s^{-2} = 10\ N\ m$ The torque required to produce an angular acceleration of $2rad/s^2$ in the body is 10 N m.		**2**
13	**Deduce the moment of inertia for the solid sphere of mass 5kg and radius 2m about an axis tangent to its surface?**	**Applying**	**2**
ANS	a. Moment of inertia of solid sphere with respect to tangent to its surface = $(7/5)\ MR^2$ b. M= 5kg, R= 2m $I =\{7 \times 5kg \times (2m)^2\}/5 = 28\ kgm^2$ Moment of inertia of solid sphere with respect to tangent to its surface is $28\ kgm^2$		**1** **1**
14	**Mass of a ring is 20g and radius is 5cm. Calculate the momentum of inertia of the ring about its diameter.**	**Applying**	**2**
ANS	a. The momentum of inertia of the ring about its diameter, $I=(1/2)\ MR^2$ b. M= 20g, R= 5cm $I =1 \times 20g \times (5cm)^2 /2 = 250\ gcm^2$ Moment of inertia of the ring about its diameter is $250\ gcm^2$		**1** **1**
15	**Find the radius of gyration of a solid uniform sphere of the radius R about its tangent.**	**Applying**	**2**
ANS	a. The Moment of Inertia of a solid uniform sphere of the radius R about its diameter = $(2/5)\ MR^2$ The Moment of Inertia of the solid uniform sphere of the radius R about its tangent = $(2/5)\ MR^2 + MR^2 = (7/5)\ MR^2$ b. The Moment of Inertia of the solid uniform sphere of the radius R about its tangent also given as MK^2 The radius of gyration of the solid uniform sphere of the radius R about its tangent = $K = \sqrt{\frac{7}{5}}R$		**1** **1**
16	**Write SI unit & dimensional formula of Moment of Inertia.**	**Understanding**	**2**
ANS	SI unit $kg.m^2$, D.F=$[ML^2T^0]$		**1** **1**

17	**During tornado, angular speed of air is very large. Explain Why?**	**Understanding**	**2**
ANS	In a tornado, As the air rushes toward the centre the MI of the air decreases. To conserve the angular momentum, the angular speed of the air increases		
18	**Define translational motion with examples.**	**Remembering & understanding**	**2**
ANS	a) A rigid body has translational motion if it moves on a horizontal surface in such a way that every particle of the rigid body has same velocity. b) examples are a car travelling in a straight line, firing of a bullet from a gun etc.		**1** **1**
19	**Define angular acceleration of a body. Write its SI unit.**	**Remembering & Understanding**	**2**
ANS	Angular acceleration of a body is defined as the ratio of the change in the angular velocity to the time interval. SI unit: rad/sec^2		**1** **1**
20	**Write SI unit & dimensional formula of torque.**	**Understanding**	**2**
ANS	SI Unit: Nm DF: $[ML^2T^{-2}]$		**1** **1**
21	**Calculate the torque about the origin for force** $\vec{F} = mg\hat{j}$ **&** $\vec{r} = x\hat{i} + y\hat{j}$	**Applying**	**2**
ANS	$\vec{\tau} = \vec{r} \times \vec{F} = (x\hat{i} + y\hat{j}) \times mg\hat{j} = mgx\hat{k}$		
22	**Write SI unit and dimensional formula of radius of gyration.**	**Understanding**	**2**
ANS	SI unit: meter DF: $[M^0LT^0]$		**1** **1**
23	**Why is MI of a body always referred as about an axis?**	**Understanding**	**2**
ANS	Due to change in the position of axis of rotation, the distance of various particles, from the axis of rotation undergo a change. Hence it is always referred as about a given axis.		
24	**A flywheel has a MI of** $2\times10^4\,kg\,m^2$ **about its axis. Determine its KE when it rotates with angular velocity of 2.5 rad/sec.**	**Applying**	**2**

ANS	$I = 2\times10^4\, Kg\, m^2, \omega = 2.5\, rad/\sec$ KE $= \frac{1}{2} I\omega^2 = 6.25\times10^4 J$		
25	**A ring has mass of 0.05Kg and radius 0.05m. What will be its MI about an axis passing through its centre & perpendicular to its plane?**	**Applying**	**2**
ANS	MI of ring about an axis passing through its centre & perpendicular to its plane $= Mr^2 = 0.05 \times 0.05^2 = 1.25 \times 10^{-4}$ Kg m^2.		
26	**State Perpendicular axes theorem of M.I.**	**Remembering**	**2**
ANS	This theorem states that the moment of inertia of a lamina about an axis perpendicular to its plane (I_Z) is equal to the sum of the M.I. of the lamina about two mutually perpendicular axes (I_X& I_Y) lie in its plane & intersecting at a point where  perpendicular axis passes. Thus, $I_{Z}= I_X + I_Y$		
27	**a. State parallel axes theorem of moment of Inertia** **b. Find the moment of inertia of a disc of mass 3kg and radius 50 cm about the following axes** **i. Axis passing though centre and perpendicular to the plane of the disc.** **ii. Axis touching the edge and perpendicular to the plane of the disc.** **iii. Axis passing through the center lying on the plane of the disc.**	**Remembering** **Applying**	**2+3=5**

<table>
<tr><td>ANS</td><td colspan="2">a. It states that the moment of Inertia (I_{AB}) of an object about an axis parallel to an axis through its center of mass(C) is equal to the sum of the moment of Inertia (I_c) of the object about the axis through its center of mass and the product of the object's mass (M) and the square of the perpendicular distance (d) bet
Mathematically, $I_{AB} = I_C + M.d^2$


Parallel axes theorem

b. The moment of inertia of a disc of mass 3kg and radius 50 cm about the following axes are :
i. Axis passing though centre and perpendicular to the plane of the disc = (1/2) $MR^2 = 0.375$ kgm^2
ii. Axis touching the edge and perpendicular to the plane of the disc = (3/2) $MR^2 = 1.125$ kgm^2
iii. Axis passing through the center lying on the plane of the disc = (1/4) $MR^2 = 0.187$ kgm^2</td><td>1
1
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1</td></tr>
<tr><td>28</td><td>a. Define angular momentum.

b. A thin ring of mass 5kg and diameter 20 cm is rotating about its axis passing through center and perpendicular to the plain at 4200rpm. Find its angular momentum.</td><td>Remembering

Applying</td><td>2+3=5</td></tr>
<tr><td>ANS</td><td colspan="2">a. Angular momentum is a vector quantity that describes the rotational motion of an object or system. It is the rotational equivalent of linear momentum.
It is given as the product of linear momentum and the perpendicular distance of the linear momentum from the axis of rotation.

In vector form, $\vec{L} = \vec{r} \times \vec{p}$

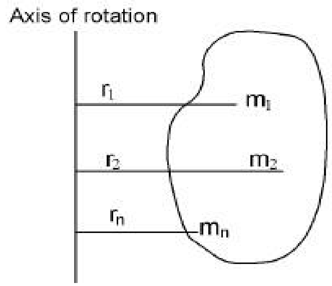
b. A thin ring of mass 5kg and diameter 20 cm is rotating about its axis at 4200rpm.
M= 5kg, d= 20cm, r= 10cm
Frequency ν = 4200 rpm = 70 rot/s
Angular velocity $\omega = 2\Pi\nu = 440$ rad/s
Its angular momentum = $L = I\omega = Mr^2\omega = 22$ kg m^2 rad s^{-1} = 22 N m s</td><td>1
1
1
1
1</td></tr>
<tr><td>29</td><td>a. Define radius of gyration?

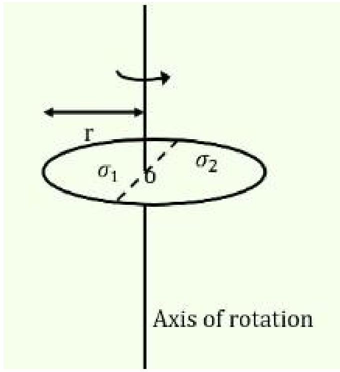
b. Derive expression for Radius of Gyration (K) for the'n' particle system.

c. The radius of gyration of a solid sphere of radius 'r' about a certain axis is 'r'. Find the distance of this axis from the center of the sphere.</td><td>Remembering

Understanding

Applying</td><td>1+2+2=5</td></tr>
</table>

ANS	a. A radius of gyration is the distance from the center of mass of a body at which the whole mass could be concentrated without changing its moment of rotational inertia about an axis through the center of mass. b. For the 'n' particle system the moment of inertia about the axis of rotation is given as $I = m_1r_1^2 + m_2r_2^2 + ...+ m_nr_n^2 = \sum_{i=1}^{n} m_i r_i^2$ If K is the radius of gyration, then $I = MK^2 = (m_1+m_2+...+m_n) K^2$  Now $\sum_{i=1}^{n} m_i r_i^2 = \sum_{i=1}^{n} m_i K^2 = \sum_{i=1}^{n} m_i K^2$ and $K = \sqrt{\frac{\sum_{i=1}^{n} m_i r_i^2}{\sum_{i=1}^{n} m_i}}$ c. The Moment of Inertia of a solid uniform sphere of the radius r about its diameter = (2/5) Mr^2 Let the distance of this axis from the center of the sphere= x Now, the Moment of Inertia of the solid uniform sphere about the axis = (2/5) $Mr^2 + Mx^2$ Again, the radius of gyration (K) of the solid uniform sphere about the axis = r Hence, $I = MK^2 = Mr^2$ i.e., $Mr^2 = (2/5) Mr^2 + Mx^2$ $x = \sqrt{(3/5)r^2}$ = 0.77 r i.e., Therefore, the distance of this axis from the center of the sphere = 0.77 r		1 1 1 1 1
30	**a. Define moment of Inertia.** **b. Two semi-circular discs of mass density $1kg/m^2$ and $2kg/m^2$, radius r =1m each are joined to form a complete disc. Find the moment of inertia of complete disc about an axis passing through its centre and perpendicular to the plain.**	**Remembering** **Applying**	**2+3=5**

ANS	a. Moment of Inertia is a measure of the rotational inertia of a body, i.e., the opposition that the body exhibits to having its speed of rotation about an axis altered by the application of a torque. It is given as the product of mass of the particle and the square of the distance of the particle from the axis of rotation. i.e. $I = Mr^2$ b. Let the mass densities of two semi-circular discs be σ_1 and σ_2. $\sigma_1 = 1$ kg /m^2 and $\sigma_2 = 2$ kg /m^2 Therefore, Mass = σ X area Mass of the complete disc = $M = m_1 + m_2 = (\sigma_1 + \sigma_2)(\pi r^2/2) = 3\pi/2$ kg Now, the moment of inertia of complete disc about an axis passing through its Centre and perpendicular to the plain is given as $I = (1/2)\,Mr^2 = 3\pi/4$ kg m^2 		1 1 1 1 1
31	**Distinguish between translational and rotational motions with examples.**	**Analyzing**	**5**
ANS	**<u>a. Translational motion</u>** 1. In Translational motion an object moves in a straight line. 2. Translational motion can be described by its displacement and direction. 3. Acceleration of Translational motion can be uniform or non-uniform. 4. Speed of Translational motion can be constant or variable. 5. Translational motion is illustrated by a car travelling in a straight line, a bullet exiting a pistol and so on b. **<u>Rotational motion</u>** 1. In Rotational motion an object turns or spins around a central point. 2. Rotational motion can be described by its angle of rotation and axis of rotation. 3. Acceleration of Rotational motion is non-uniform due to centripetal force. 4. Speed of Rotational motion is constant unless there is friction. 5. Rotational motion can be seen in a ceiling fan, a potter's wheel or a vehicle's wheel.		**0.5** **0.5** **0.5** **0.5** **0.5** **0.5** **0.5** **0.5** **0.5** **0.5**
32	**If the Earth were to suddenly contract to half of its original size, by how much would the day be decreased? Given** MI of Earth $= \frac{2}{5}MR^2$	**Applying**	**5**

ANS	MI of Earth before contraction $I_1 = \frac{2}{5}MR^2$ After contraction $I_2 = \frac{2}{5}M\left(\frac{R}{2}\right)^2 = \frac{2}{5}\frac{MR^2}{4} = \frac{I_1}{4}$ According the law of conservation of angular momentum $I_1\omega_1 = I_2\omega_2$ $\Rightarrow I_1\frac{2\pi}{T_1} = I_2\frac{2\pi}{T_2}$ $\Rightarrow T_2 = \frac{I_2}{I_1}T_1$ $\Rightarrow T_2 = \frac{T_1}{4} = 24/4 = 6hr$ Hence day will be decreased by 24-6=18hrs.		
33	**State & Explain Law of conservation of angular momentum.**	**Remembering & understanding**	**5**
ANS	Statement: Angular momentum of a system remains constant if no external torque acts on it. W.K.T $\vec{L} = I\vec{\omega}$ Def. both side w.r.t. t, we get $\frac{d\vec{L}}{dt} = \frac{d}{dt}(I\vec{\omega})$ But $\frac{d\vec{L}}{dt} = \vec{\tau}$ So $\vec{\tau} = \frac{d}{dt}(I\vec{\omega})$ If the net external torque acting on the body is zero then,		**1** **4**

	$\frac{d}{dt}(I\vec{\omega}) = 0 \Rightarrow I\vec{\omega} = const. \Rightarrow \vec{L} = const.$ Which is the Law of conservation of angular momentum.		
34	**Derive an expression showing the relationship between torque & MI. & hence define MI.**	**Applying**	**5**
ANS	Wk.t. torque acting on a rigid body moving on the action of force $\vec{F}$ about an axis of rotation at a distance is given by $\vec{\tau} = \vec{r} \times \vec{F} = rF\sin\theta = rF$ (if $\vec{F} \perp \vec{r}$) Now $\vec{F} = ma \Rightarrow \tau = rma$ But $a = r\alpha$, where α is angular acceleration. So $\tau = mr^2\alpha$, but $I = mr^2$ (MI of the body about the given axis of rotation.) Hence $\tau = I\alpha$ If $\alpha = 1 rad/\sec^2$ then $\tau = I$ So MI of the body about a given axis is numerically equal to the external torque required to produce unit angular acceleration in the body about that axes.		**4** **1**
35	**A force** $\vec{F} = \left(2\hat{i} + 3\hat{j} - 2\hat{k}\right)N$ **acts on a particle whose coordinates are** $(1m, 2m, -2m)$ **. Find the torque on the particle.**	**Applying**	**5**
ANS	Given $\vec{F} = \left(2\hat{i} + 3\hat{j} - 2\hat{k}\right)N$ $\vec{r} = \left(1\hat{i} + 2\hat{j} - 2\hat{k}\right)m$ Using formula $\vec{\tau} = \vec{r} \times \vec{F}$ we get $\vec{\tau} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ 1 & 2 & -2 \\ 2 & 3 & -2 \end{vmatrix} = 2\hat{i} - 2\hat{j} - \hat{k}$		

	Magnitude= $\left\|\vec{\tau}\right\| = \sqrt{2^2 + (-2)^2 + (-1)^2} = 3Nm$		
36	**Find the MI of disc** **i. about its diameter** **ii. tangent perpendicular to its plane.**	**Applying**	**5**
ANS	i. $I_z = I_x + I_y = 2I_x = 2I_y$ $\Rightarrow I_x = I_y = \frac{1}{2} I_z = \frac{1}{2}\left(\frac{1}{2}MR^2\right) = \frac{1}{4}MR^2$ (by perpendicular theorem) ii. $I_t = \frac{1}{2}MR^2 + MR^2 = \frac{3}{2}MR^2$ (by parallel axis theorem)		**2.5** **2.5**