Exercise-1

✎ Marked Questions can be used as Revision Questions.

PART - I : SUBJECTIVE QUESTIONS

Section (A) : Kinematics

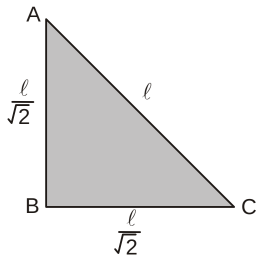
A-1. A uniform disk rotating with constant angular acceleration covers 50 revolutions in the first five seconds after the start. Calculate the angular acceleration and the angular velocity at the end of five seconds.

A-2. A body rotating with 20 rad/s is acted upon by a uniform torque providing it an angular deceleration of 2 rad/s^2. At which time will the body have kinetic energy same as the initial value if the torque acts continuously ?

Section (B) : Moment of inertia

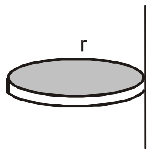
B-1. Calculate the moment of inertia of a uniform square plate of mass M and side L about one of its diagonals, with the help of its moment of inertia about its centre of mass.

B-2.✎ A uniform triangular plate of mass M whose vertices are ABC has lengths ℓ, $\frac{\ell}{\sqrt{2}}$ and $\frac{\ell}{\sqrt{2}}$ as shown in figure. Find the moment of inertia of this plate about an axis passing through point B and perpendicular to the plane of the plate.



B-3. Find the moment of inertia of a uniform half-disc about an axis perpendicular to the plane and passing through its centre of mass. Mass of this disc is M and radius is R.

B-4. Calculate the radius of gyration of a uniform circular disk of radius r and thickness t about a line perpendicular to the plane of this disk and tangent to the disk as shown in figure.



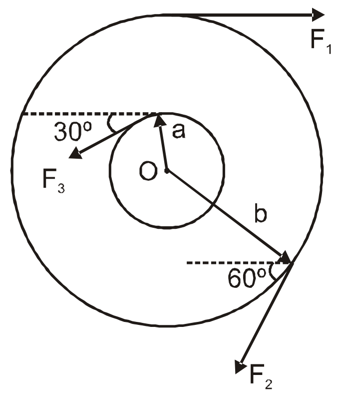
Section (C) : Torque

C-1. Two forces $\vec{F}_1 = 2\hat{i} - 5\hat{j} - 6\hat{k}$ and $\vec{F}_2 = -\hat{i} + 2\hat{j} - \hat{k}$ are acting on a body at the points (1, 1, 0) and (0, 1, 2) respectively. Find torque acting on the body about point (–1, 0, 1).

C-2. A simple pendulum having bob of mass m and length ℓ is pulled aside to make an angle θ with the vertical. Find the magnitude of the torque of the weight of the bob about the point of suspension. At which position its torque is zero? At which θ it is maximum?

C-3. A particle having mass m is projected with a speed v at an angle α with horizontal ground. Find the torque of the weight of the particle about the point of projection when the particle (a) is at the highest point. (b) reaches the ground.

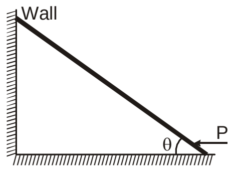
C-4. Calculate the net torque on the system about the point O as shown in figure if F_1 = 11 N, F_2 = 9 N, F_3 = 10 N, a = 10 cm and b = 20 cm. (All the forces along the tangent.)



Section (D) : Rotational Equilibrium

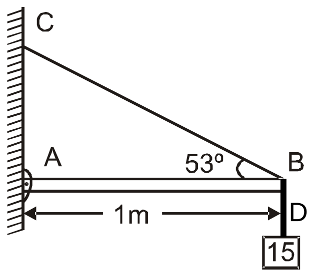
D-1. A uniform metre stick having mass 400 g is suspended from the fixed supports through two vertical light strings of equal lengths fixed at the ends. A small object of mass 100 g is put on the stick at a distance of 60 cm from the left end. Calculate the tensions in the two strings. ($g = 10\ m/s^2$)

D-2. Assuming frictionless contacts, determine the magnitude of external horizontal force P applied at the lower end for equilibrium of the rod as shown in figure. The rod is uniform and its mass is ' m'.



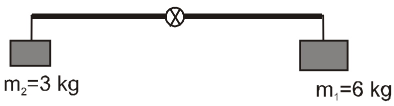
D-3. A uniform ladder having length 10.0 m and mass 24 kg is resting against a vertical wall making an angle of 53° with it. The vertical wall is smooth but the ground surface is rough. A painter weighing 75 kg climbs up the ladder. If he stays on the ladder at a point 2 m from the upper end, what will be the normal force and the force of friction on the ladder by the ground? What should be the minimum coefficient of friction between ground and ladder for the painter to work safely? ($g = 10\ m/s^2$)

D-4. In the system as shown in figure, AB is a uniform rod of mass 10 kg and BC is a light string which is connected between wall and rod, in vertical plane. There is block of mass 15 kg connected at B with a light string. [Take $g = 10\ m/s^2$] (BC and BD are two different strings)
If whole of the system is in equilibrium then find
(i) Tension in the string BC
(ii) Hinge force exerted on beam at point A



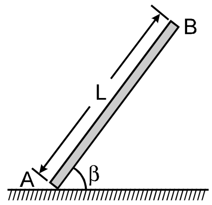
Section (E) : Rotation about fixed axis ($\tau_H = I_H\alpha$)

E-1. A rod of negligible mass having length ℓ = 2 m is pivoted at its centre and two masses of m_1 = 6 kg and m_2 = 3 kg are hung from the ends as shown in figure.

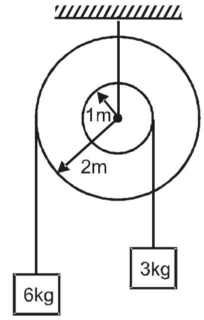


(a) Find the initial angular acceleration of the rod if it is horizontal initially.
(b) If the rod is uniform and has a mass of m_3 = 3 kg.
(i) Find the initial angular acceleration of the rod.
(ii) Find the tension in the supports to the blocks of mass 3 kg and 6 kg ($g = 10\ m/s^2$).

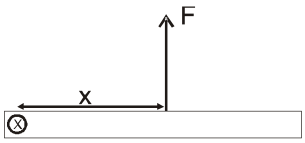
E-2. The uniform rod AB of mass m is released from rest when $\beta = 60^{\circ}$. Assuming that the friction force between end A and the surface is large enough to prevent sliding, determine (for the instant just after release)
(a) The angular acceleration of the rod
(b) The normal reaction and the friction force at A.



E-3. The moment of inertia of the pulley system as shown in the figure is 3 kg – m^2. The radii of bigger and smaller pulleys are 2m and 1m respectively. As the system is released from rest, find the angular acceleration of the pulley system. (Assume that there is no slipping between string & pulley and string is light) [Take g = 10 m/s^2]

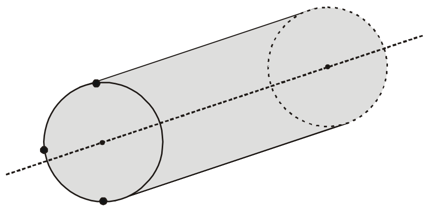


E-4. A uniform thin rod of length L is hinged about one of its ends and is free to rotate about the hinge without friction. Neglect the effect of gravity. A force F is applied at a distance x from the hinge on the rod such that force is always perpendicular to the rod. Find the normal reaction at the hinge as function of 'x', at the initial instant when the angular velocity of rod is zero.

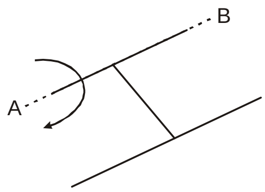


Section (F) : Rotation about Fixed Axis (Energy conservation)

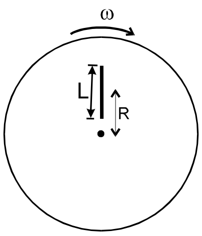
F-1. A solid cylinder of mass M = 1kg & radius R = 0.5m is pivoted at its centre & has three particles of mass m = 0.1kg mounted at its perimeter in the vertical plane as shown in the figure. The system is initially at rest. Find the angular speed of the cylinder, when it has swung through 90_0 in anticlockwise direction. [Take g = 10 m/s^2]



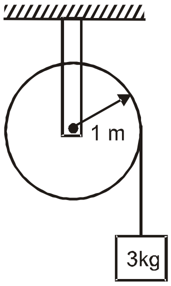
F-2. A rigid body is made of three identical uniform thin rods each of length L fastened together in the form of letter H. The body is free to rotate about a fixed horizontal axis AB that passes through one of the legs of the H. The body is allowed to fall from rest from a position in which the plane of H is horizontal. What is the angular speed of the body, when the plane of H is vertical.



F-3. A uniform rod of mass m and length L lies radially on a disc rotating with angular speed ω in a horizontal plane about its axis. The rod does not slip on the disc and the centre of the rod is at a distance R from the centre of the disc. Find out the kinetic energy of the rod.



F-4. The moment of inertia of the pulley system as shown in figure is 3 kgm^2. Its radius is 1m. The system is released from rest find the linear velocity of the block, when it has descended through 40 cm. (Assume that there is no slipping between string & pulley and string is light) [Take g = 10 m/s^2]

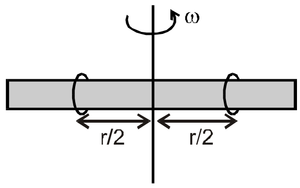


Section (G) : Angular Momentum & its conservation

G-1. A particle having mass 2 kg is moving with velocity $(2\hat{i}+3\hat{j})$m/s. Find angular momentum of the particle about origin when it is at (1, 1, 0).

G-2. A particle having mass 2 kg is moving along straight line 3x + 4y = 5 with speed 8m/s. Find angular momentum of the particle about origin. x and y are in meters.

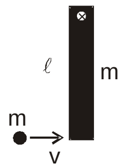
G-3. Two beads (each of mass m) can move freely in a frictionless wire whose rotational inertia with respect to the vertical axis is I. The system is rotated with an angular velocity ω_0 when the beads are at a distance r/2 from the axis. What is the angular velocity of the system when the beads are at a distance r from the axis ? **[JEE - 1990]**



G-4. A system consists of two identical small balls of mass 2 kg each connected to the two ends of a 1 m long light rod. The system is rotating about a fixed axis through the centre of the rod and perpendicular to it at an angular speed of 9 rad/s. An impulsive force of average magnitude 10 N acts on one of the masses in the direction of its velocity for 0.20 s. Calculate the new angular velocity of the system.

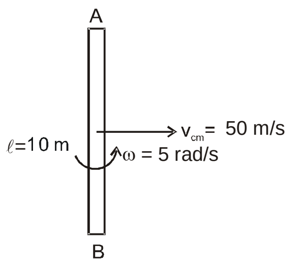
G-5. A uniform round board of mass M and radius R is placed on a fixed smooth horizontal plane and is free to rotate about a fixed axis which passes through its centre. A man of mass m is standing on the point marked A on the circumference of the board. At first the board & the man are at rest. The man starts moving along the rim of the board at constant speed v_o relative to the board. Find the angle of board's rotation when the man passes his starting point on the disc first time.

G-6. A point object of mass m moving horizontally hits the lower end of the uniform thin rod of length □ and mass m and sticks to it. The rod is resting on a horizontal, frictionless surface and pivoted at the other end as shown in figure. Find out angular velocity of the system just after collision.

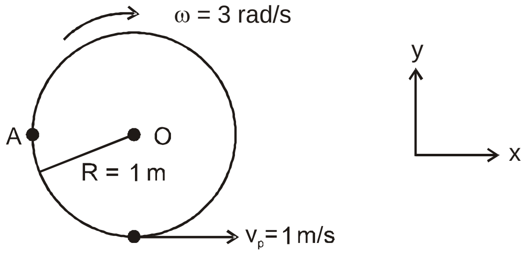


Section (H) : Combined Translational & Rotation Motion (Kinematics)

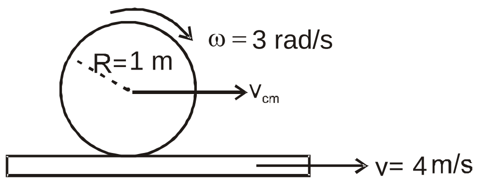
H-1 The centre of mass of a uniform rod of length 10 meter is moving with a translational velocity of 50 m/sec. on a frictionless horizontal surface as shown in the figure and the rod rotates about its centre of mass with an angular velocity of 5 radian/sec. Find out V_A and V_B



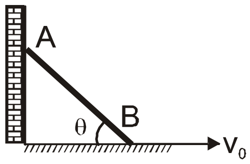
H-2 A ring of radius 1 m. performs combined translational and rotational motion on a frictionless horizontal surface with an angular velocity of 3 rad/sec as shown in the figure. Find out velocity of its centre and point A if the velocity of the lowest point V_P is 1 m/sec.



H-3 A plank is moving with a velocity of 4 m/sec. A disc of radius 1 m rolls without slipping on it with an angular velocity of 3 rad/sec as shown in figure. Find out the velocity of centre of the disc.

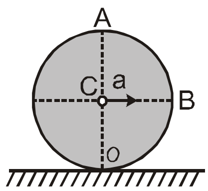


H-4 The end B of uniform rod AB which makes angle θ with the floor is being pulled with a velocity v_0 as shown. Taking the length of the rod as ℓ, calculate the following at the instant when $\theta = 37^o$



(a) The velocity of end A (b) The angular velocity of rod (c) Velocity of CM of the rod.

H-5. A ball of radius R = 10.0 cm rolls without slipping on a horizontal plane so that its centre moves with constant acceleration a = 2.50 cm/s^2; t = 2.00 s after the beginning of motion its position corresponds to that shown in Fig. Find :



(a) the velocities of the points A, B and O

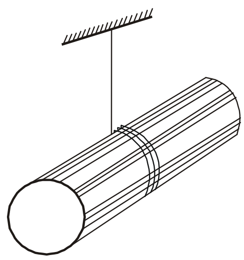
(b) the accelerations of these points.

Section (I) : Combined translational & Rotational Motion (Dynamics)

I-1. A small solid cylinder is released from a point at a height h on a rough as track shown in figure. Assuming that it does not slip anywhere, calculates its linear speed when it rolls on the horizontal part of the track.

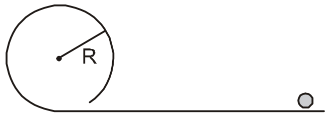
I-2. A uniform ball of mass ‘m’ rolls without sliding on a fixed horizontal surface. The velocity of the lowest point of the ball with respect to the centre of the ball is V. Find out the total kinetic energy of the ball.

I-3. A string is wrapped over the curved surface of a uniform solid cylinder and the free end is fixed with rigid support. The solid cylinder moves down, unwinding the string. Find the downward acceleration of the solid cylinder.

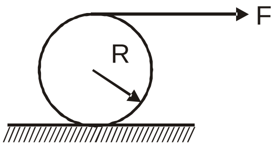


I-4. A uniform disk of mass m is released from rest from the rim of a fixed hemispherical bowl so that it rolls along the surface. If the rim of the hemisphere is kept horizontal, find the normal force exerted by the bowl on the disk when it reaches the bottom of the bowl.

I-5. There is a rough track, a portion of which is in the form of a cylinder of radius R as shown in the figure. Find the minimum linear speed of a uniform ring of radius r with which it should be set rolling without sliding on the horizontal part so that it can complete round the circle without sliding on the cylindrical part.



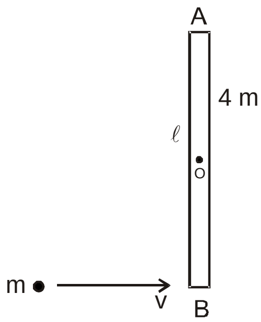
I-6. A uniform solid sphere of radius R is placed on a smooth horizontal surface. It is pulled by a by constant force acting along the tangent from the highest point. Calculate the distance travelled by the centre of mass of the solid sphere during the time it makes one full revolution.



I-7. A uniform hollow sphere of mass m = 1 kg is placed on a rough horizontal surface for which the coefficient of static friction between the surfaces in contact is $\mu = 2/5$. Find the maximum constant force which can be applied at the highest point in the horizontal direction so that the sphere can roll without slipping. (Take $g = 10\ m/s^2$)

Section (J) : Conservation of angular momentum (Combined translation & rotational motion)

J-1 A uniform rod of length ℓ and mass 4m lies on a frictionless horizontal surface on which it is free to move anyway. A ball of mass m moving with speed v as shown in figure.collides with the rod at one of the ends. If ball comes to rest immediately after collision then find out angular velocity ω of rod just after collistion.



J-2. A uniform rod having mass m_1 and length L lies on a smooth horizontal surface. A particle of mass m_2 moving with speed u on the horizontal surface strikes the free rod perpendicularly at an end and it sticks to the rod.

(a) Calculate the velocity of the com C of the system constituting "the rod plus the particle".

(b) Calculate the velocity of the particle with respect to C before the collision.

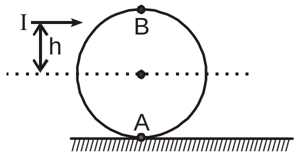
(c) Calculate the velocity of the rod with respect to C before the collision

(d) Calculate the angular momentum of the particle and of the rod about the com C before the collision.

(e) Calculate the moment of inertia of the rod plus particle about the vertical axis through the centre of mass C after the collision.

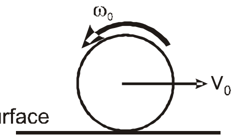
(f) Calculate the velocity of the com C and the angular velocity of the system about the centre of mass after the collision.

J-3. A uniform solid sphere is placed on a smooth horizontal surface. An impulse I is given horizontally to the sphere at a height h = 4R/5 above the centre line. m and R are mass and radius of sphere respectively.



(a) Find angular velocity of sphere & linear velocity of centre of mass of the sphere after impulse.
(b) Find the minimum time after which the highest point B will touch the ground,
(c) Find the displacement of the centre of mass during this interval.

J-4. A uniform disc of radius R = 0.2 m kept over a rough horizontal surface is given velocity v_0 and angular velocity ω_0. After some time its kinetic energy becomes zero. If v_0 = 10 m/s, find ω_0.



Section (K) : Toppling

K-1. A solid cubical block of mass m and side a slides down a rough inclined plane of inclination θ with a constant speed. Calculate the torque of the normal force acting on the block about its centre and the perpendicular distance 'x' from centre of mass at which it is acting.

PART - II : ONLY ONE OPTION CORRECT TYPE

Section (A) : Kinematics

A-1. A fan is running at 3000 rpm. It is switched off. It comes to rest by uniformly decreasing its angular speed in 10 seconds. The total number of revolutions in this period.
(A) 150 (B) 250 (C) 350 (D) 300

A-2. A block hangs from a string wrapped on a disc of radius 20 cm free to rotate about its axis which is fixed in a horizontal position. If the angular speed of the disc is 10 rad/s at some instant, with what speed is the block going down at that instant ?
(A) 4 m/s (B) 3 m/s (C) 2 m/s (D) 5 m/s

Section (B) : Moment of inertia

B-1. A uniform circular disc A of radius r is made from a copper plate of thickness t and another uniform circular disc B of radius 2r is made from a copper plate of thickness t/2. The relation between the moments of inertia I_A and I_B is
(A) $I_A > I_B$ (B) $I_A = I_B$
(C) $I_A < I_B$ (D) depends on the values of t and r.

B-2. The moment of inertia of a non-uniform semicircular wire having mass m and radius r about a line perpendicular to the plane of the wire through the centre is
(A) mr^2 (B) $\frac{1}{2}mr^2$ (C) $\frac{1}{4}mr^2$ (D) $\frac{2}{5}mr^2$

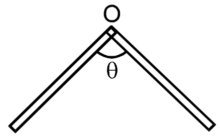
B-3. Let I_A and I_B be the moments of inertia of two solid cylinders of identical geometrical shape and size about their axes, the first made of aluminium and the second of iron.
(A) $I_A < I_B$ (B) $I_A = I_B$ (C) $I_A > I_B$
(D) relation between I_A and I_B depends on the actual shapes of the bodies.

B-4. Let I_1 and I_2 be moments of inertia of a body about two axes 1 and 2 respectively, The axis 1 passes through the centre of mass of the body but axis 2 does not.
(A) $I_1 < I_2$ (B) If $I_1 < I_2$, the axes are parallel.
(C) If the axes are parallel, $I_1 < I_2$ (D) If the axes are not parallel, $I_1 \geq I_2$.

B-5. The moment of inertia of an elliptical disc of uniform mass distribution of mass 'm', semi major axis 'r', semi minor axis 'd' about its axis is :

(A) $= \frac{mr^2}{2}$ (B) $= \frac{md^2}{2}$ (C) $> \frac{mr^2}{2}$ (D) $< \frac{mr^2}{2}$

B-6. A unifrom thin rod of length L and mass M is bent at the middle point O as shown in figure. Consider an axis passing through its middle point O and perpendicular to the plane of the bent rod. Then moment of inertia about this axis is :

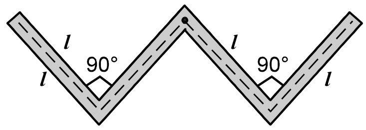


(A) $\frac{2}{3}$ mL^2 (B) $\frac{1}{3}$ mL^2 (C) $\frac{1}{12}$ mL^2 (D) dependent on θ

B-7. The moment of inertia of a uniform circular disc about its diameter is 200 gm cm^2. Then its moment of inertia about an axis passing through its center and perpendicular to its circular face is

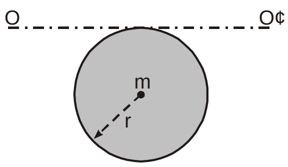
(A) 100 gm cm^2 (B) 200 gm cm^2 (C) 400 gm cm^2 (D) 1000 gm cm^2

B-8. A thin uniform rod of length 4 *l*, mass 4m is bent at the points as shown in the fig. What is the moment of inertia of the rod about the axis passing point O & perpendicular to the plane of the paper.



(A) $\frac{m\ell^2}{3}$ (B) $\frac{10\,m\ell^2}{3}$ (C) $\frac{m\ell^2}{12}$ (D) $\frac{m\ell^2}{24}$

B-9. Moment of inertia of a uniform disc about the axis O O′ is:

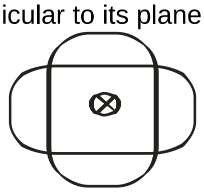


(A) $\frac{3\,m\,r^2}{2}$ (B) $\frac{m\,r^2}{2}$ (C) $\frac{5\,m\,r^2}{2}$ (D) $\frac{5\,m\,r^2}{4}$

B-10. The moment of inertia of a hollow cubical box of mass M and side a about an axis passing through the centres of two opposite faces is equal to

(A) $\frac{5Ma^2}{3}$ (B) $\frac{5Ma^2}{6}$ (C) $\frac{5Ma^2}{12}$ (D) $\frac{5Ma^2}{18}$

B-11. A uniform thin rod of length (4a + 2πa) and of mass (4m + 2πm) is bent and fabricated to form a square surrounded by semicircles as shown in the figure. The moment of inertia of this frame about an axis passing through its centre and perpendicular to its plane is **[Olympiad 2014 (stage-1)]**



(A) $\frac{(4+2\pi)}{3}ma^2$ (B) $\frac{(4+\pi)}{2}ma^2$ (C) $\frac{(4+3\pi)}{3}ma^2$ (D) $\frac{ma^2\{10+3\pi\}}{3}$

Section (C) : Torque

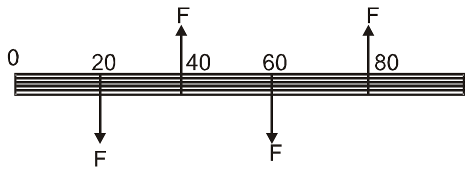
C-1. If a rigid body is subjected to two forces $\vec{F}_1 = 2\hat{i}+3\hat{j}+4\hat{k}$ acting at (3, 3, 4) and $\vec{F}_2 = -2\hat{i}-3\hat{j}-4\hat{k}$ acting at (1, 0, 0) then which of the following is (are) true? **[REE - 1994]**
(A) The body is in equilibrium.
(B) The body is under the influence of a torque only.
(C) The body is under the influence of a single force.
(D) The body is under the influence of a force together with a torque .

C-2. A force $\vec{F} = 4\hat{i} - 10\hat{j}$ acts on a body at a point having position vector $-5\hat{i} - 3\hat{j}$ relative to origin of co-ordinates on the axis of rotation. The torque acting on the body about the origin is :
(A) $38\hat{k}$ (B) $-25\hat{k}$ (C) $62\hat{k}$ (D) none of these

C-3. In case of torque of a couple if the axis is changed by displacing it parallel to itself, torque will :
(A) increase (B) decrease (C) remain constant (D) None of these

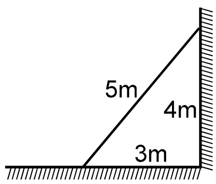
Section (D) : RotationAL Equilibrium

D-1. Four equal and parallel forces are acting on a rod (as shown in figure) in horizontal plane at distances of 20 cm, 40 cm, 60 cm and 80 cm respectively from one end of the rod. Under the influence of these forces the rod :



(A) is at rest (B) experiences a torque
(C) experiences a linear motion (D) experiences a torque and also a linear motion

D-2. A uniform ladder of length 5m is placed against the wall in vertical plane as shown in the figure. If coefficient of friction μ is the same for both the wall and the floor then minimum value of μ for it not to slip is

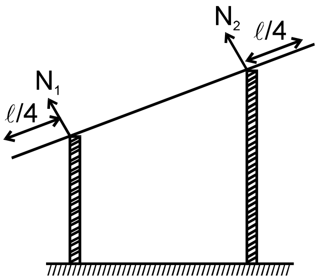


(A) $\mu = 1/2$ (B) $\mu = 1/4$ (C) $\mu = 1/3$ (D) $\mu = 1/5$

D-3 A rod of weight w is supported by two parallel knife edges A & B and is in equilibrium in a horizontal position. The knives are at a distance d from each other. The centre of mass of the rod is at a distance *x* from A. The normal reactions at A and B will be :
(A) $N_A = 2w(1 - x/d)$, $N_B = wx/d$] (B) $N_A = w(1 - x/d)$, $N_B = wx/d$]
(C) $N_A = 2w(1 - x/d)$, $N_B = 2wx/d$] (D) $N_A = w(2 - x/d)$, $N_B = wx/d$]

D-4 The beam and pans of a balance have negligible mass. An object weighs W_1 when placed in one pan and W_2 when placed in the other pan. The weight W of the object is :
(A) $\sqrt{W_1W_2}$ (B) $\sqrt{(W_1+W_2)}$ (C) $W_1^2 + W_2^2$ (D) $(W_1^{-1} + W_2^{-1})/2$

D-5. A uniform rod of length □ is placed symmetrically on two walls as shown in figure. The rod is in equilibrium. If N_1 and N_2 are the normal forces exerted by the walls on the rod then



(A) $N_1 > N_2$ (B) $N_1 > N_2$
(C) $N_1 = N_2$ (D) N_1 and N_2 would be in the vertical directions.

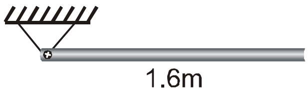
Section (E) : Rotation about Fixed axis ($\tau_H = I_H\alpha$)

E-1. A uniform circular disc A of radius r is made from a metal plate of thickness t and another uniform circular disc B of radius 4r is made from the same metal plate of thickness t/4. If equal torques act on the discs A and B, initially both being at rest. At a later instant, the angular speeds of a point on the rim of A and another point on the rim of B are ω_A and ω_B respectively. We have
(A) $\omega_A > \omega_B$ (B) $\omega_A = \omega_B$ (C) $\omega_A < \omega_B$
(D) the relation depends on the actual magnitude of the torques.

E-2. A body is rotating with constant angular velocity about a vertical axis fixed in an inertial frame. The net force on a particle of the body not on the axis is
(A) horizontal and skew with the axis (B) vertical
(C) horizontal and intersecting the axis (D) none of these.

E-3. One end of a uniform rod having mass m and length ℓ is hinged. The rod is placed on a smooth horizontal surface and rotates on it about the hinged end at a uniform angular velocity ω. The force exerted by the hinge on the rod has a horizontal component
(A) $m\omega^2\ell$ (B) zero (C) mg (D) $\frac{1}{2}m\omega^2\ell$

E-4. The uniform rod of mass 20 kg and length 1.6 m is pivoted at its end and swings freely in the vertical plane. Angular acceleration of rod just after the rod is released from rest in the horizontal position as shown in figure is



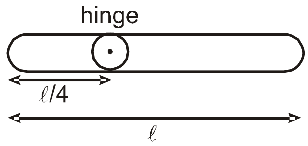
(A) $\frac{15g}{16}$ (B) $\frac{17g}{16}$ (C) $\frac{16g}{15}$ (D) $\frac{g}{15}$

E-5. Two men support a uniform horizontal rod at its two ends. If one of them suddenly lets go, the force exerted by the rod on the other man just after this moment will:
(A) remain unaffected (B) increase (C) decrease
(D) become unequal to the force exerted by him on the rod.

Section (F) : Rotation about fixed axis (energy conservation)

F-1. A uniform metre stick is held vertically with one end on the floor and is allowed to fall. The speed of the other end when it hits the floor assuming that the end at the floor does not slip :
(A) $\sqrt{4g}$ (B) $\sqrt{3g}$ (C) $\sqrt{5g}$ (D) $\sqrt{g}$

F-2. A uniform rod is hinged as shown in the figure and is released from a horizontal position. The angular velocity of the rod as it passes the vertical position is: (axis is fixed, smooth and horizontal)



(A) $\sqrt{\frac{12g}{3\ell}}$ (B) $\sqrt{\frac{2g}{3\ell}}$ (C) $\sqrt{\frac{24g}{7\ell}}$ (D) $\sqrt{\frac{3g}{7\ell}}$

Section (G) : Angular Momentum & its conservation

G-1. A constant torque actingon a uniform circular wheel changes its angular momentum from A_0 to $4A_0$ in 4 sec. the magnitude of this torque is :

(A) $4A_0$ (B) A_0 (C) $3A_0 /4$ (D) $12A_0$

G-2. A particle moves with a constant velocity parallel to the Y-axis. Its angular momentum about the origin.

(A) is zero (B) remains constant (C) goes on increasing (D) goes on decreasing.

G-3. A particle is projected at time t = 0 from a point P on the ground with a speed V_0, at an angle of 45° to the horizontal. What is the magnitude of the angular momentum of the particle about P at time $t = v_0/g$.

(A) $\frac{mv_0^2}{2\sqrt{2}g}$ (B) $\frac{mv_0^3}{\sqrt{2}g}$ (C) $\frac{mv_0^2}{\sqrt{2}g}$ (D) $\frac{mv_0^3}{2\sqrt{2}g}$

G-4. A uniform thin circular ring of mass 'M' and radius 'R' is rotating about its fixed axis passing through its centre perpendicular to its plane of rotation with a constant angular velocity ω. Two objects each of mass m, are attached gently to the opposite ends of a diameter of the ring. The ring now rotates with an angular velocity. **[JEE - 1983]**

(A) $\frac{\omega M}{(M+m)}$ (B) $\frac{\omega M}{(M+2m)}$ (C) $\frac{\omega M}{(M-2m)}$ (D) $\frac{\omega(M+3m)}{M}$

G-5. A boy sitting firmly over a rotating stool has his arms folded. If he stretches his arms, his angular momentum about the axis of rotation

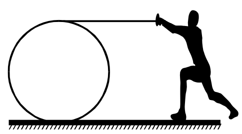
(A) increases (B) decreases (C) remains unchanged (D) doubles

Section (H) : Combined Translational + Rotational Motion (Kinematics)

H-1. The centre of a disc rolling without slipping on a plane surface moves with speed u. A particle, on the lower half of the rim making an angle 60º with vertical, will be moving at speed

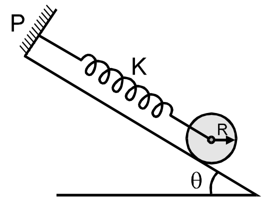
(A) zero (B) u (C) $\sqrt{2}u$ (D) 2u

H-2. A thin string is wrapped several times around a cylinder kept on a rough horizontal surface. A boy standing at a distance □ from the cylinder draws the string towards him as shown in figure. The cylinder rolls without slipping. The length of the string passed through the hand of the boy while the cylinder reaches his hand is



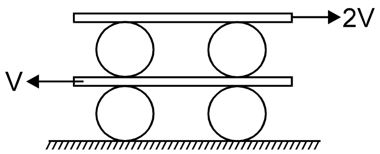
(A) □ (B) 2□ (C) 3□ (D) 4□

H-3. A uniform cylinder of mass M and radius R rolls without slipping down a slope of angle θ to the horizontal. The cylinder is connected to a spring constant K while the other end of the spring is connected to a rigid support at P. The cylinder is released when the spring is unstretched. The maximum displacement of cylinder is



(A) $\frac{3}{4}\frac{Mg\sin\theta}{K}$ (B) $\frac{Mg\sin\theta}{K}$ (C) $\frac{2Mg\sin\theta}{K}$ (D) $\frac{4}{3}\frac{Mg\sin\theta}{K}$

H-4. A system of uniform cylinders and plates is shown in figure. All the cylinders are identical and there is no slipping at any contact. Velocity of lower & upper plate is V and 2V respectively as shown in figure. Then the ratio of angular speed of the upper cylinders to lower cylinders is

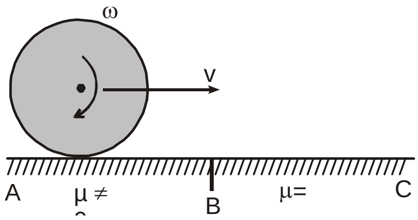


(A) 3 (B) 1/3 (C) 1 (D) none of these

H-5. When a person throws a meter stick it is found that the centre of the stick is moving with a speed of 10 m/s vertically upwards & left end of stick with a speed of 20 m/s vertically upwards. Then the angular speed of the stick is:
(A) 20 rad/ sec (B) 10 rad/sec (C) 30 rad/sec (D) none of these

Section (I): Combined translational & Rotational Motion (Dynamics)

I-1. As shown in the figure, a uniform disc of mass m is rolling without slipping with a angular velocity ω. The portion AB is rough and BC is smooth. When it crosses point B disc will be in :



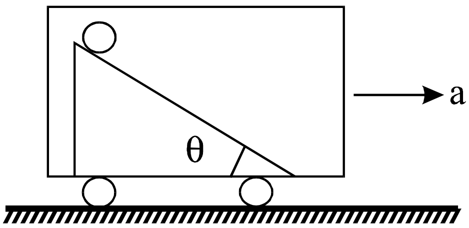
(A) translational motion only (B) pure rolling motion
(C) rotational motion only (D) none of these

I-2. A solid sphere, a hollow sphere and a ring, all having equal mass and radius, are placed at the top of an incline and released. The friction coefficients between the objects and the incline are equal but not sufficient to allow pure rolling. The greastest kinetic energy at the bottom of the incline will be achieved by
(A) the solid sphere (B) the hollow sphere (C) the ring
(D) all will achieve same kinetic energy.

I-3. A hollow sphere and a solid sphere having equal mass and equal radii are rolled down without slipping on a rough inclined plane.
(A) The two spheres reach the bottom simultaneously
(B) The hollow sphere reaches the bottom with lesser speed.
(C) The solid sphere reaches the bottom with greater kinetic energy
(D) The two spheres will reach the bottom with same linear momentum

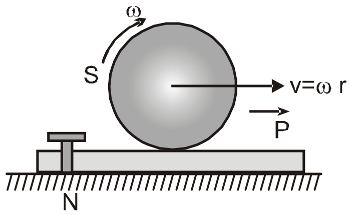
I-4. A solid sphere, a hollow sphere and a solid cylinder, all having equal mass and radius, are placed at the top of an incline and released. The friction coefficients between the objects and the incline are equal but not sufficient to allow pure rolling. Greastest time will be taken in reaching the bottom by
(A) the solid sphere (B) the hollow sphere (C) the solid cylinder (D) all will take same time.

I-5. A rough inclined plane fixed in a car accelerating on a horizontal road is shown in figure. The angle of incline θ is related to the acceleration a of the car as $a = g \tan\theta$. If a rigid sphere is set in pure rolling on the incline



(A) it will continue pure rolling (B) Friction will act on it
(C) its angular velocity will increase (D) its angular velocity will decrease.

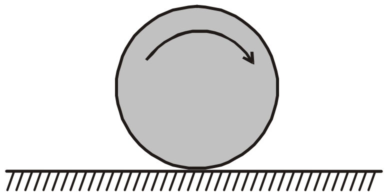
I-6. A sphere S rolls without slipping, moving with a constant speed on a plank P. The friction between the upper surface of P and the sphere is sufficient to prevent slipping, while the lower surface of P is smooth and rests on the ground. Initially, P is fixed to the ground by a pin N. If N is suddenly removed:



(A) S will begin to slip on P
(B) P will begin to move backwards
(C) the speed of S will decrease and its angular velocity will increase
(D) there will be no change in the motion of S and P will still be at rest.

I-7. A body is given translational velocity and kept on a surface that has sufficient friction. Then:
(A) body will move forward before pure rolling
(B) body will move backward before pure rolling
(C) body will start pure rolling immediately
(D) none of these

I-8. A body of mass m and radius r is rotated with angular velocity ω as shown in the figure & kept on a surface that has sufficient friction then the body will move :



(A) backward first and then move forward
(B) forward first and then move backward
(C) will always move forward
(D) none of these

I-9. A body of mass m and radius R rolling horizontally without slipping at a speed v climbs a ramp to a height $\frac{3v^2}{4g}$. The rolling body can be **[Olympiad 2015 (stage-1)]**
(A) a sphere
(B) a circular ring
(C) a spherical shell
(D) a circular disc

Section (J) : Conservation of angular momentum (combined translation & rotational motion)

J-1. A sphere is released on a smooth inclined plane from the top. When it moves down its angular momentum is:

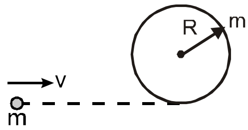
(A) conserved about every point

(B) conserved about the point of contact only

(C) conserved about the centre of the sphere only

(D) conserved about any point on a fixed line parallel to the inclined plane and passing through the centre of the ball.

J-2. A circular wooden loop of mass m and radius R rests flat on a horizontal frictionless surface. A bullet, also of mass m, and moving with a velocity V, strikes the loop and gets embedded in it. The thickness of the loop is much smaller than R. The angular velocity with which the system rotates just after the bullet strikes the loop is



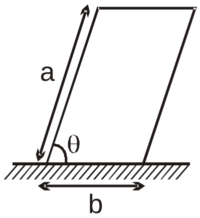
(A) $\frac{V}{4R}$ (B) $\frac{V}{3R}$ (C) $\frac{2V}{3R}$ (D) $\frac{3V}{4R}$

Section (K) : Toppling

K-1. A uniform cube of side a and mass m rests on a rough horizontal table. A horizontal force 'F' is applied normal to one of the faces at a point that is directly above the centre of the face, at a height $\frac{3a}{4}$ above the base. The minimum value of 'F' for which the cube begins to tilt about the edge is (assume that the cube does not slide). **[JEE - 1984]**

(A) $\frac{2}{3}mg$ (B) $\frac{4}{3}mg$ (C) $\frac{5}{4}mg$ (D) $\frac{1}{2}mg$

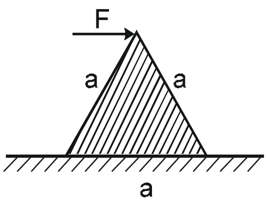
K-2. A homogenous block having its cross-section to be a parallelogram of sides 'a' and 'b' (as shown) is lying at rest and is in equilibrium on a smooth horizontal surface. Then for acute angle θ :



(A) $\cos\theta \le \frac{b}{a}$ (B) $\cos\theta \ge \frac{b}{a}$ (C) $\cos\theta < \frac{b}{a}$ (D) $\cos\theta > \frac{b}{a}$

(E) $\cos\theta > \frac{a}{b}$

K-3. An equilateral uniform prism of mass m rests on a rough horizontal surface with coefficient of friction μ. A horizontal force F is applied on the prism as shown in the figure. If the coefficient of friction is sufficiently high so that the prism does not slide before toppling, then the minimum force required to topple the prism is :

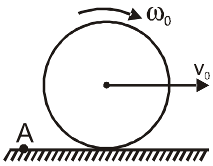


(A) $\frac{mg}{\sqrt{3}}$ (B) $\frac{mg}{4}$ (C) $\frac{\mu mg}{\sqrt{3}}$ (D) $\frac{\mu mg}{4}$

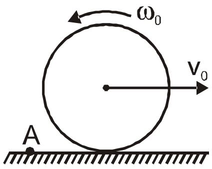
PART - III : MATCH THE COLUMN

1. In each situation of column-I, a uniform disc of mass m and radius R rolls on a rough fixed horizontal surface as shown in the figure. At t = 0 (initially) the angular velocity of disc is ω_o and velocity of centre of mass of disc is v_o (in horizontal direction). The relation between v_o and ω_o for each situation and also initial sense of rotation is given for each situation in column-I. Then match the statements in column-I with the corresponding results in column-II.

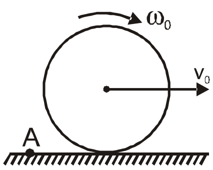
Column-I

(A) 

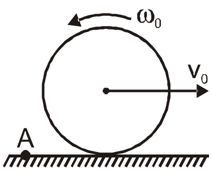
($v_o > R\,\omega_o$)

(B) 

($v_o > R\,\omega_o$)

(C) 

($v_o < R\,\omega_o$)

(D) 

($v_o < R\,\omega_o$)

Column-II

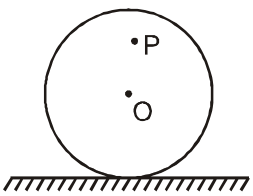
(p) The angular momentum of disc about point A (as shown in figure) remains conserved.

(q) The kinetic energy of disc after it starts rolling without slipping is less than its initial kinetic energy.

(r) In the duration disc rolls with slipping, the friction acts on disc towards left.

(s) In the duration disc rolls with slipping, the friction acts on disc for some time towards right and for some time towards left.

2. A uniform disc rolls without slipping on a rough horizontal surface with uniform angular velocity. Point O is the centre of disc and P is a point on disc as shown in the figure. In each situation of column I a statement is given and the corresponding results are given in column-II. Match the statements in column-I with the results in column-II.



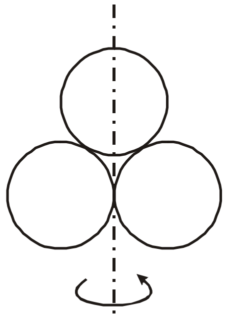
Column I	Column II
(A) The velocity of point P on disc	(p) Changes in magnitude with time.
(B) The acceleration of point P on disc	(q) is always directed from that point (the point on disc given in column-I) towards centre of disc.
(C) The tangential acceleration of point P on disc	(r) is always zero.
(D) The acceleration of point on disc which is in contact with rough horizontal surface	(s) is non-zero and remains constant in magnitude.

Exercise-2

✎ **Marked Questions can be used as Revision Questions.**

PART - I : ONLY ONE OPTION CORRECT TYPE

1. Three rings each of mass m and radius r are so placed that they touch each other. The radius of gyration of the system about the axis as shown in the figure is :

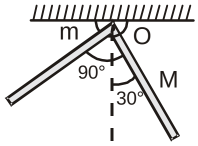


(A) $\sqrt{\frac{6}{5}}\ r$ (B) $\sqrt{\frac{5}{6}}\ r$ (C) $\sqrt{\frac{6}{7}}\ r$ (D) $\sqrt{\frac{7}{6}}\ r$

2. A hollow cylinder has mass M, outside radius R_2 and inside radius R_1. Its moment of inertia about an axis parallel to its symmetry axis and tangential to the outer surface is equal to :

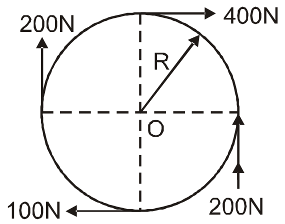
(A) $\frac{M}{2}(R_2^2 + R_1^2)$ (B) $\frac{M}{2}(R_2^2 - R_1^2)$ (C) $\frac{M}{4}(R_2 + R_1)^2$ (D) $\frac{M}{2}(3R_2^2 + R_1^2)$

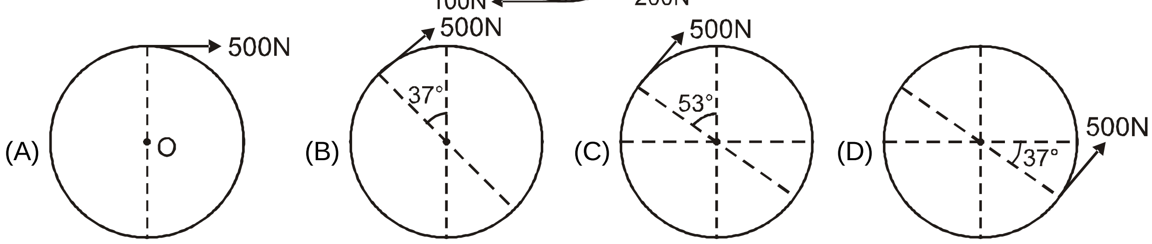
3. Two uniform rods of equal length but different masses are rigidly joined to form an L–shaped body, which is then pivoted about O as shown in the figure. If in equilibrium the body is in the shown configuration, ratio M/m will be:



(A) 2 (B) 3 (C) $\sqrt{2}$ (D) $\sqrt{3}$

4. Four forces tangent to the circle of radius 'R' are acting on a wheel as shown in the figure. The resultant equivalent one force system will be :

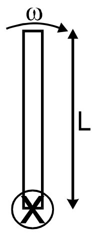




5. A uniform thin rod of mass 'm' and length L is held horizontally by two vertical strings attached to the two ends. One of the string is cut. Find the angular acceleration soon after it is cut :

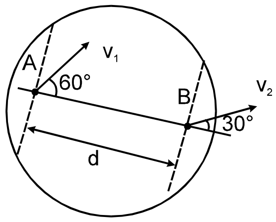
(A) $\frac{g}{2L}$ (B) $\frac{g}{L}$ (C) $\frac{3g}{2L}$ (D) $\frac{2g}{L}$

6. A uniform rod hinged at its one end is allowed to rotate in vertical plane. Rod is given an angular velocity ω in its vertical position as shown in figure. The value of ω for which the force exerted by the hinge on rod is zero in this position is :



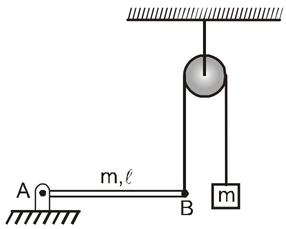
(A) $\sqrt{\frac{g}{L}}$ (B) $\sqrt{\frac{2g}{L}}$ (C) $\sqrt{\frac{g}{2L}}$ (D) $\sqrt{\frac{3g}{L}}$

7. Two points A & B on a disc have velocities v_1 & v_2 at some moment. Their directions make angles 60° and 30° respectively with the line of separation as shown in figure. The angular velocity of disc is :



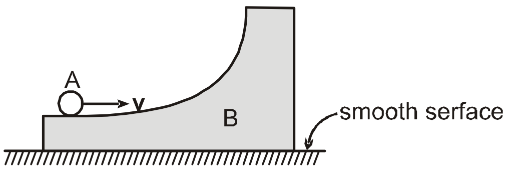
(A) $\frac{\sqrt{3}v_1}{d}$ (B) $\frac{v_2}{\sqrt{3}d}$ (C) $\frac{v_2 - v_1}{d}$ (D) $\frac{v_2}{d}$

8. Uniform rod AB is hinged at the end A in a horizontal position as shown in the figure (the hinge is frictionless, that is, it does not exert any friction force on the rod). The other end of the rod is connected to a block through a massless string as shown. The pulley is smooth and massless. Masses of the block and the rod are same and are equal to ' m '. Acceleration due to gravity is g. The tension in the thread, and angular acceleration of the rod just after release of block from this position



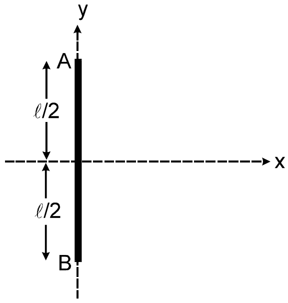
(A) $\frac{3mg}{8}$, $\frac{g}{8\ell}$ (B) $\frac{5mg}{8}$, $\frac{3g}{8\ell}$ (C) $\frac{mg}{8}$, $\frac{5g}{8\ell}$ (D) $\frac{7mg}{8}$, $\frac{7g}{8\ell}$

9. In the figure shown a ring A is rolling without sliding with a velocity v on the horizontal surface of the body B (of same mass as A). All surfaces are smooth. B has no initial velocity. What will be the maximum height (from initial position) reached by A on B.



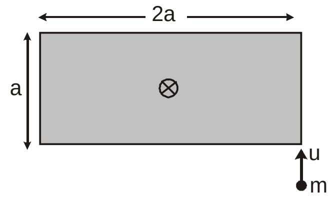
(A) $\frac{3\,v^2}{4\,g}$ (B) $\frac{v^2}{4\,g}$ (C) $\frac{v^2}{2\,g}$ (D) $\frac{v^2}{3\,g}$

10. A uniform rod of mass m, length □ is placed over a smooth horizontal surface along y-axis and is at rest as shown in figure. An impulsive force F is applied for a small time Δt along x-direction at point A after this rod moves freely. The x–coordinate of end A of the rod when the rod becomes parallel to x–axis for the first time is (initially the coordinate of centre of mass of the rod is (0, 0)) :



(A) $\frac{\pi\ell}{12}$ (B) $\frac{\ell}{2}\left(1+\frac{\pi}{12}\right)$ (C) $\frac{\ell}{2}\left(1-\frac{\pi}{6}\right)$ (D) $\frac{\ell}{2}\left(1+\frac{\pi}{6}\right)$

11. A uniform rectangular plate of mass m which is free to rotate about the smooth vertical hinge passing through the centre and perpendicular to the plate, is lying on a smooth horizontal surface. A particle of mass m moving with speed 'u' collides with the plate and sticks to it as shown in figure. The angular velocity of the plate after collision will be :

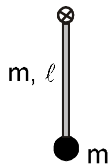


(A) $\frac{12}{5}\frac{u}{a}$ (B) $\frac{12}{19}\frac{u}{a}$ (C) $\frac{3}{2}\frac{u}{a}$ (D) $\frac{3}{5}\frac{u}{a}$

12. A rod can rotate about a fixed vertical axis. The mass is non-uniformly distributed along the length of the rod. A horizontal force of constant magnitude and always perpendicular to the rod is applied at the end. Which of the following quantity (after one rotation) will not depend on the information that through which end the axis passes ? (Assuming initial angular velocity to be zero)

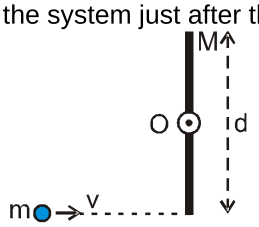
(A) angular momentum (B) kinetic energy (C) angular velocity (D) none of these

13. A particle is attached to the lower end of a uniform rod which is hinged at its other end as shown in the figure. The minimum speed given to the particle so that the rod performs circular motion in a vertical plane will be : [length of the rod is □, consider masses of both rod and particle to be same]



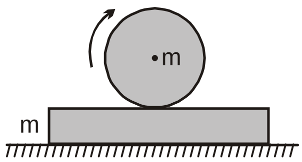
(A) $\sqrt{5g\ell}$ (B) $\sqrt{4g\ell}$ (C) $\sqrt{4.5g\ell}$ (D) none of these

14. A particle of mass m is moving horizontally at speed v perpendicular to a uniform rod of length d and mass M = 6m. The rod is hinged at centre O and can freely rotate in horizontal plane about a fixed vertical axis passing through its centre O. The hinge is frictionless.The particle strikes and sticks to the end of the rod. The angular speed of the system just after the collision :



(A) 2v/3d (B) 3v/2d (C) v/3d (D) 2v/d

15. A uniform sphere of mass ' m ' is given some angular velocity about a horizontal axis through its centre and gently placed on a plank of mass ' m '. The co-efficient of friction between the two is μ. The plank rests on a smooth horizontal surface. The initial acceleration of the centre of sphere relative to the plank will be :



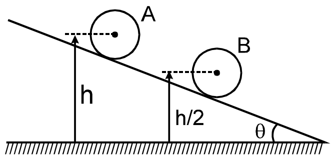
(A) zero (B) μg (C) (7/5) μg (D) 2 μg

16. A rod of negligible mass and length ℓ is pivoted at the point $\ell/4$ distance from the left end as shown. A particle of mass m is fixed to its left end & another particle of mass 2 m is fixed to the right end. If the system is released from rest and after sometime becomes vertical, the speed v of the two masses and angular velocity at that instant is

(A) $\frac{1}{4}\sqrt{\frac{40g\ell}{19}}, \frac{3}{4}\sqrt{\frac{40g\ell}{19}}, \sqrt{\frac{40g}{19\ell}}$ (B) $\frac{1}{2}\sqrt{\frac{20g\ell}{19}}, \frac{3}{4}\sqrt{\frac{20g\ell}{19}}, \sqrt{\frac{20g}{19\ell}}$

(C) $\frac{1}{4}\sqrt{\frac{20g\ell}{19}}, \frac{3}{4}\sqrt{\frac{20g\ell}{19}}, \sqrt{\frac{20g}{19\ell}}$ (D) $\frac{1}{2}\sqrt{\frac{40g\ell}{19}}, \frac{1}{2}\sqrt{\frac{40g\ell}{19}}, \sqrt{\frac{40g}{19\ell}}$

17. Two identical balls A & B of mass m each are placed on a fixed wedge as shown in figure. Ball B is kept at rest and it is released just before two balls collide. Ball A rolls down without slipping on inclined plane & collides elastically with ball B. The kinetic energy of ball A just after the collision with ball B is (Neglect friction between A and B, also neglect the radius of the balls) :

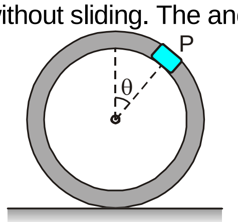


(A) $\frac{mgh}{7}$ (B) $\frac{mgh}{2}$ (C) $\frac{2mgh}{5}$ (D) $\frac{7mgh}{5}$

18. A solid uniform disc of mass m rolls without slipping down an inclined plane with an acceleration a. The frictional force on the disc due to surface of the plane is

(A) 2 ma (B) $\frac{3}{2}$ ma (C) ma (D) $\frac{1}{2}$ ma

19. A small block of mass 'm' is rigidly attached at 'P' to a ring of mass '3m' and radius 'r'. The system is released from rest at $\theta = 90°$ and rolls without sliding. The angular acceleration of ring just after release is

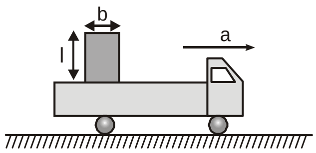


(A) $\frac{g}{4r}$ (B) $\frac{g}{8r}$ (C) $\frac{g}{3r}$ (D) $\frac{g}{2r}$

20. A uniform ring of radius R is given a back spin of angular velocity $V_0/2R$ and thrown on a horizontal rough surface with velocity of center to be V_0. The velocity of the centre of the ring when it starts pure rolling will be

(A) $V_0/2$ (B) $V_0/4$ (C) $3V_0/4$ (D) 0

21. A box of dimensions ℓ and b is kept on a truck moving with an acceleration a. If box does not slide, maximum acceleration for it to remain in equilibrium (w.r.t.truck) is :



(A) $\frac{g\ell}{b}$ (B) $\frac{gb}{\ell}$

(C) g (D) none of these

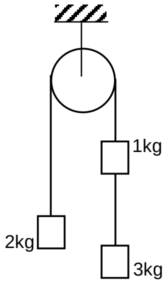
22. If the positions of two like parallel forces on a light rod are interchanged, their resultant shifts by one–fourth of the distance between them then the ratio of their magnitude is:

(A) 1 : 2 (B) 2 : 3 (C) 3 : 4 (D) 3 : 5

23. Consider two point masses m_1 and m_2 connected by alight rigid rod of length r_0. The moment of inertia of the system about an axis passing through their centre of mass and perpendicular to the rigid rod is given by **[Olympiad (Stage-1) 2017]**

(A) $\frac{m_1m_2}{2(m_1+m_2)}r_0^2$ (B) $\frac{m_1m_2}{m_1+m_2}r_0^2$ (C) $\frac{2m_1m_2}{m_1+m_2}r_0^2$ (D) $\frac{m_1^2+m_2^2}{m_1+m_2}r_0^2$

24._ In the following arrangement the pulley is assumed to be light and the string inextensible. The acceleration of the system can be determined by considering conservation of a certain physical quantity. The physical quantity conserved and the acceleration respectively, are **[Olympiad (Stage-1) 2017]**



(A) energy and g/3 (B) linear momentum and g/2
(C) angular momentum and g/3 (D) mass and g/2

PART - II : SINGLE AND DOUBLE VALUE INTEGER TYPE

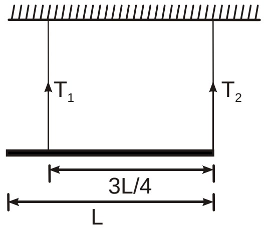
1. A wheel starting from rest is uniformly accelerated at 2 rad/s^2 for 20 seconds. It rotates uniformly for the next 20 seconds and is finally brought to rest in the next 20 seconds. Total angular displacement of the wheel is n × 10^2 radian where n is.

2. Two steel balls of equal diameter are connected by a rigid bar of negligible weight as shown & are dropped in the horizontal position from height h above the heavy steel and brass base plates. If the coefficient of restitution between the ball & steel base is 0.6 & that between the other ball & the brass base is 0.4. The angular velocity of the bar immediately after rebound is n×10^{-2} rad/s where n is : (Assume the two impacts are simultaneous.) (g = 9.8m/s^2)

3. Three identical uniform rods, each of length, are joined to form a rigid equilateral triangle. Its radius of gyration about an axis passing through a corner and perpendicular to the plane of the triangle is $\frac{\ell}{\sqrt{n}}$ where n is :

4. The moment of inertia of a thin uniform rod of mass m & length ℓ about an axis passing through one end & making angle θ = 45º with its length is $\frac{m\ell^2}{n}$ where n is.

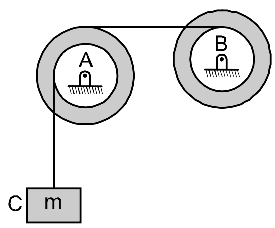
5. A uniform rod of mass m and length L is suspended with two massless strings as shown in the figure. If the rod is at rest in a horizontal position the ratio of tension in the two strings T_1/T_2 is:



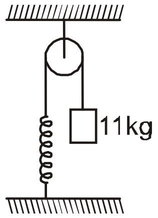
6. Two persons of equal height are carrying a long uniform wooden beam of length ℓ. They are at distance ℓ/4 and ℓ/6 from nearest ends of the rod. The ratio of normal reactions at their heads is n : 3 where n is :

7. A (i) ring and (ii) uniform disc both of radius R is given an angular velocity and then carefully placed on a horizontal surface such that its axis is vertical. If the coefficient of friction is μ for both cases then the ratio of the time taken by the ring and disk to come to rest is n : 3 where n is : (The pressure exerted by the disc and ring on the surface can be regarded as uniform).

8. Each of the double pulleys shown has a centroidal mass moment of inertia of 'mr^2', inner radius r and an outer radius 2r. Assuming that the bearing friction of hinge at A and at B is equivalent to torque of magnitude $\frac{mgr}{4}$ then the tension (in N) in the string connecting the pulleys is : (m = 3kg, g = 10m/s^2, and r =0.1m)

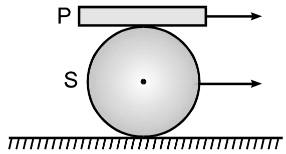


9. The pulley shown in figure has a radius of 10 cm and moment of inertia 0.1 kg-m^2. The string going over it attached at one end to a vertical spring of spring constant 100 N/m fixed from below, and supports a 11 kg mass at the other end. The system is released from rest with the spring at its natural length. Find the speed (in m/s) of the block when it has descended through 10 cm. (Take g = 10 m/s^2 and assume that the there is no slipping between string and pulley).



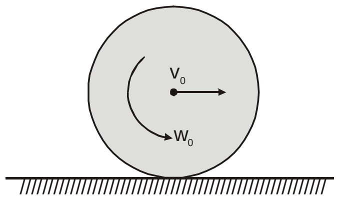
10. The angular momentum of a particle about origin is varying as L = $4\sqrt{2}$ t + 8 (SI units) when it moves along a straight line y = x – 4 (x, y in meters). The magnitude of force (in N) acting on the particle would be :

11. A plank P is placed on a solid cylinder S, which rolls on a horizontal surface. The two are of equal mass. There is no slipping at any of the surfaces in contact. The ratio of the kinetic energy of P to the kinetic energy of S is n : 3 where n is :

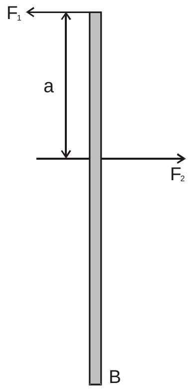


12. A uniform rod of mass m = 5.0 kg and length ℓ = 90 cm rests on a smooth horizontal surface. One of the ends of the rod is struck with the impulse J = 3.0 N-s in a horizontal direction perpendicular to the rod and removed. As a result of which the rod gets angular velocity and linear velocity instantaneously. The force (in N) with which one half of the rod will act on the other in the process of motion later on.

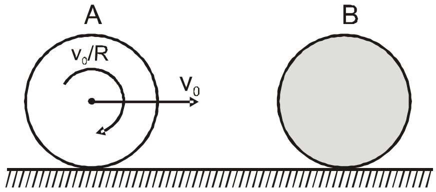
13. A uniform solid sphere of mass m and radius r is projected along a rough horizontal surface with the initial velocity v_0 and angular velocity ω_0 as shown in the figure. If the sphere finally comes to complete rest then $\frac{2\omega_0 r}{v_0}$ is equal to :



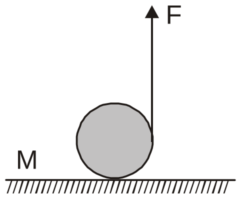
14. A thin uniform rod AB of mass m = 1.0 kg moves translationally with acceleration w = 2.0 m/s^2 due to two antiparallel forces F_1 and F_2 (Fig.). The distance between the points at which these forces are applied is equal to a = 20 cm. Besides, it is known that F_2 = 5.0.N. Find the length (in m) of the rod.



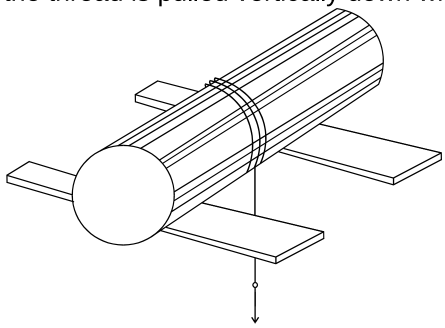
15. A hollow smooth uniform sphere A of mass 'm' rolls without sliding on a smooth horizontal surface. It collides elastically and headon with another stationary smooth solid sphere B of the same mass m and same radius. The ratio of kinetic energy of 'B' to that of 'A' just after the collision is 3 : n where n is :



16. The free end of the string wound on the surface of a solid cylinder of mass M = 1kg & radius R = $\frac{2}{3}$ m is pulled up by a force F as shown. If there is sufficient friction between cylinder & floor then the upper limit to the angular acceleration (in rad/s^2) of the cylinder for which it rolls without slipping is : (g = 10m/s^2)



17. A uniform solid cylinder of mass m = 1kg rests on two horizontal planks. A thread is wound on the cylinder. The hanging end of the thread is pulled vertically down with a constant force F.

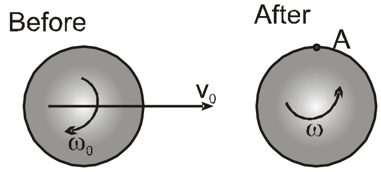


(a) Find the maximum magnitude of the force F(in N) which still does not bring about any sliding of the cylinder, if the coefficient of friction between the cylinder and the planks is equal to $\mu = \frac{1}{3}$.

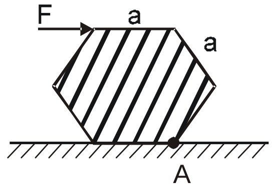
(b) The acceleration a_{max} of the axis of the cylinder rolling on the planks is $\frac{n}{3}$ m/s^2 where n is:

18. A cylinder rotating at an angular speed of 50 rev/s is brought in contact with an identical stationary cylinder. Because of the kinetic friction, torques act on the two cylinders, accelerating the stationary one and decelerating the moving one. If the common magnitude of the angular acceleration and deceleration be1 rev/s^2, then how much time (ins) will it take before the two cylinders have equal angular speed ?

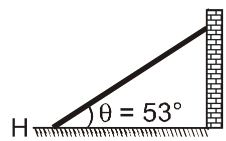
19. A uniform disc of mass M = 1kg, radius R = 1m is moving towards right on smooth horizontal surface with velocity v_0 = 20 m/s & having angular velocity ω_0 = 4 rad/s about the perpendicular axis outward the plane of disc passing through centre of disc. Suddenly top point of the disc gets hinged about a fixed smooth axis. The angular velocity (in rad/s) of disk about new rotation axis is:



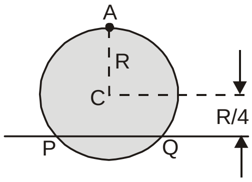
20. A regular hexagonal uniform block of mass m = $4\sqrt{3}$ kg rests on a rough horizontal surface with coefficient of friction μ as shown in figure. A constant horizontal force is applied on the block as shown. If the coefficient of friction is sufficient to prevent slipping before toppling, then the minimum force(in N) required to topple the block about its corner A is:(g = 10m/s^2)



21. A uniform rod of length ℓ = 1m is kept as shown in the figure. H is a horizontal smooth surface and W is a vertical smooth wall. The rod is released from this position. The angular acceleration (in radian/sec^2) of the rod just after the release is :



22. A uniform circular disc has radius R & mass m. A particle also of mass m is fixed at a point A on the edge of the disc as shown in the figure. The disc can rotate freely about a fixed horizontal chord PQ that is at a distance R/4 from the centre C of the disc. The line AC is perpendicular to PQ. Initially the disc is held vertical with the point A at its highest position. It is then allowed to fall so that it starts rotating about PQ. The linear speed of the particle as it reaches its lowest position is $\sqrt{ngR}$, where n is an integer. Find the value of n **[JEE - 1998' 8/200]**



PART - III : ONE OR MORE THAN ONE OPTIONS CORRECT TYPE

1. A rigid body is in pure rotation.

(A) You can find two points in the body in a plane perpendicular to the axis of rotation having same velocity.

(B) You can find two points in the body in a plane perpendicular to the axis of rotation having same acceleration.

(C) Speed of all the particles lying on the curved surface of a cylinder whose axis coincides with the axis of rotation is same.

(D) Angular speed of the body is same as seen from any point in the body.

2. A sphere is rotating uniformly about a fixed axis passing through its centre then:

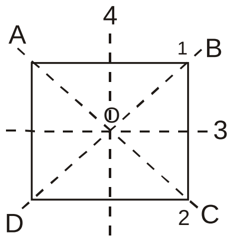
(A) The particles on the surface of the sphere do not have any angular acceleration.

(B) The particles on the axis do not have any linear acceleration

(C) Different particles on the surface have same angular speeds.

(D) All the particles on the surface have same linear speed

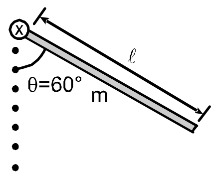
3. The moment of inertia of a thin uniform square plate ABCD of uniform thickness about an axis passing through the centre O and perpendicular to the plate is - **[REE - 1992]**



(A) $I_1 + I_2$ (B) $I_3 + I_4$ (C) $I_1 + I_3$ (D) $I_1 + I_2 + I_3 + I_4$

where I_1, I_2, I_3, and I_4 are respectively the moments of inertia about axes 1, 2, 3, and 4 which are in the plane of the plate.

4. In the figure shown a uniform rod of mass m and length □□is hinged. The rod is released when the rod makes angle $\theta = 60°$ with the vertical.



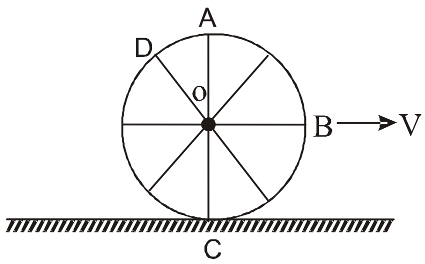
(A) The angular acceleration of the rod just after release is $\frac{3\sqrt{3}g}{4\ell}$

(B) The normal reaction due to the hinge just after release is $\frac{\sqrt{19}mg}{8}$

(C) The angular velocity of the rod at the instant it becomes vertical is $\sqrt{\frac{3g}{2\ell}}$

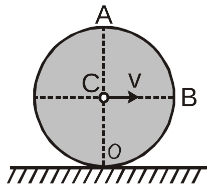
(D)The normal reaction due to the hinge at the instant the rod becomes vertical is $\frac{7}{4}$ mg

5. Consider a disc rolling without slipping on a horizontal surface at a linear speed V as shown in figure



(A) the speed of the particle A is 2V
(B) the speed of B, C and D are all equal to V
(C) the speed of C is zero and speed of B is $\sqrt{2}V$
(D) the speed of O is less than the speed of B

6. A cylinder rolls without slipping over a horizontal plane with constant velocity. The radius of the cylinder is equal to r. At this moment



(A) The speed of B is $\sqrt{2}$ times the speed of A.
(B) The radius of curvature of trajectory traced out by A is 4r.
(C) The radius of curvature of trajectory traced out by B is $2\sqrt{2}$ r.
(D) The radius of curvature of trajectory traced out by C is r.

7. A uniform solid sphere is released from rest from the top of an inclined plane of inclination θ. Then choose the correct option(s).

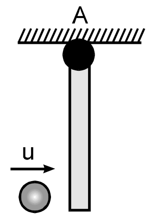
(A) The minimum coefficient of friction between sphere and the incline to prevent slipping is $\frac{2}{7}\tan\theta$.
(B) The kinetic energy of solid sphere as it moves down a distance S on the incline is mgSsinθ if $\mu \geq \frac{2}{7}\tan\theta$.
(C) The magnitude of work done by friction on the solid sphere is less than μmgScosθ as it moves down a distance S on the incline if $\mu \geq \frac{2}{7}\tan\theta$.
(D) The magnitude of work done by friction on the solid sphere is equal to μmgScosθ as it moves down a distance S on the incline if $\mu \geq \frac{2}{7}\tan\theta$.

8. A uniform solid cylinder rolls without slipping on a rough horizontal floor, its centre of mass moving with a speed v. It makes an elastic collision with smooth vertical wall. After impact:
(A) its centre of mass will move with a speed *v* initially
(B) its motion will be rolling without slipping immediately
(C) its motion will be rolling with slipping initially and its rotational motion will stop momentarily at some instant
(D) its motion will be rolling without slipping only after some time.

9. If $\vec{\tau} \times \vec{L} = 0$ for a rigid body, where $\vec{\tau}$ = resultant torque & $\vec{L}$ = angular momentum about a point and both are non-zero. Then :
(A) $\vec{L}$ may be constant (B) $|\vec{L}|$ = constant (C) $|\vec{L}|$ may decrease (D) $|\vec{L}|$ may increase

10. In absence of external forces on a rigid system, which of the following quantities must remain constant?
(A) angular momentum
(B) linear momentum
(C) moment of inertia about fixed axis through any point on body
(D) kinetic energy

11. In the given figure a ball strikes a rod elastically and rod is smoothly hinged at point A. Then which of the statement(s) is/are correct for the collision?

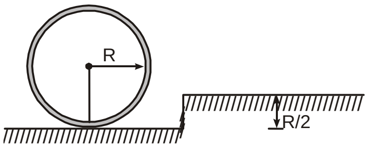


(A) linear momentum of system (ball + rod) is conserved
(B) angular momentum of system about hinged point A is conserved
(C) initial KE of the system is equal to final KE of the system
(D) linear momentum of ball is conserved.

12. A horizontal disc rotates freely about a vertical fixed axis through its centre. A ring, having the same mass and radius as the disc, is now gently placed on the disc coaxially. After some time the two rotate with a common angular velocity:

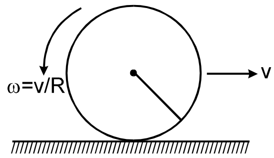
(A) some friction exists between the disc and the ring before achieving common angular velocity
(B) the angular momentum of the 'disc plus ring' about axis of rotation is conserved
(C) the final common angular velocity is 2/3rd of the initial angular velocity of the disc
(D) The final common angular velocity is 1/3rd of the initial angular velocity of the disc

13. A wheel (to be considered as a ring) of mass m and radius R rolls without sliding on a horizontal surface with constant velocity v. It encounters a step of height R/2 at which it ascends without sliding.



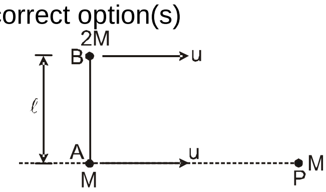
(A) the angular velocity of the ring just after it comes in contact with the step is 3v/4R
(B) the normal reaction due to the step on the wheel just after the impact is $\frac{mg}{2} - \frac{9\,mv^2}{16\,R}$
(C) the normal reaction due to the step on the wheel increases as the wheel ascends
(D) the friction will be absent during the ascent.

14. A hollow sphere is set into motion on a rough horizontal surface with a speed v in the forward direction and an rotational speed v/R in the anticlockwise direction as shown in figure. Find the translational speed of the sphere (a) when it stops rotating and (b) when slipping finally ceases and pure rolling starts.



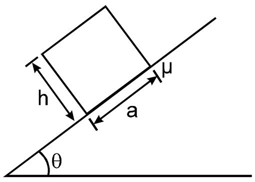
(A) The angular momentum of the sphere about its centre of mass is conserved.
(B) The speed of the sphere at the instant it stops rotating momentarily is v/3
(C) The speed of the sphere after pure rolling starts is v/5
(D) Work done by fricition upto pure rolling starts is zero.

15. Two small particles A and B of masses M and 2M respectively, are joined rigidly to the ends of a light rod of length □ as shown in the figure. The system translates on a smooth horizontal surface with a velocity u in a direction perpendicular to the rod. A particle P of mass M kept at rest on the surface sticks to the particle A as the particle P collides with it. Then choose the correct option(s)



(A) The speed of particle A just after collision is $\frac{u}{2}$
(B) The speed of particle B just after collision is $\frac{u}{2}$
(C) The velocity of centre of mass of system A+B+P is $\frac{3u}{4}$
(D) The angular speed of the system A+B+P after collision is $\frac{u}{2\ell}$

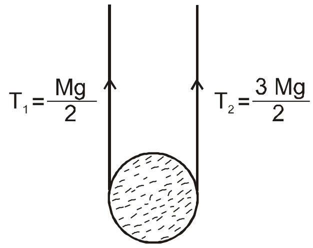
16. A block with a square base measuring a × a and height h, is placed on an inclined plane. The coefficient of friction is μ. The angle of inclination (θ) of the plane is gradually increased. The block will:



(A) topple before sliding if $\mu > \frac{a}{h}$
(B) topple before sliding if $\mu < \frac{a}{h}$
(C) slide before toppling if $\mu > \frac{a}{h}$
(D) slide before toppling if $\mu < \frac{a}{h}$

17. A uniform disc of mass M and radius R is lifted using a string as shown in the figure. Then,

[**Olympiad 2014 (stage-1)**]



(A) its linear acceleration is g upward

(B) its linear acceleration is g downward

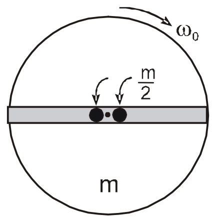
(C) its angular acceleration is $\frac{2g}{R}$.

(D) its rate of change of angular momentum is MgR.

PART - IV : COMPREHENSION

Comprehension-1

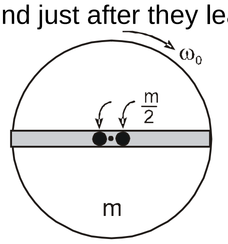
A uniform disc of mass 'm' and radius R is free to rotate in horizontal plane about a vertical smooth fixed axis passing through its centre. There is a smooth groove along the diameter of the disc and two small balls of mass $\frac{m}{2}$ each are placed in it on either side of the centre of the disc as shown in fig. The disc is given initial angular velocity ω_0 and released.



1. The angular speed of the disc when the balls reach the end of the disc is :

(A) $\frac{\omega_0}{2}$ (B) $\frac{\omega_0}{3}$ (C) $\frac{2\omega_0}{3}$ (D) $\frac{\omega_0}{4}$

2. The speed of each ball relative to ground just after they leave the disc is :



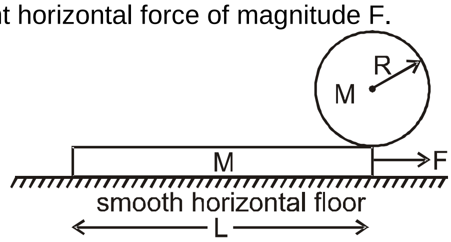
(A) $\frac{R\omega_0}{\sqrt{3}}$ (B) $\frac{R\omega_0}{\sqrt{2}}$ (C) $\frac{2R\omega_0}{3}$ (D) $\frac{R\omega_0}{3}$

3. The net work done by forces exerted by disc on one of the ball for the duration ball remains on the disc is

(A) $\frac{2mR^2\omega_0^2}{9}$ (B) $\frac{mR^2\omega_0^2}{18}$ (C) $\frac{mR^2\omega_0^2}{6}$ (D) $\frac{mR^2\omega_0^2}{9}$

Comprehension-2

A uniform disc of mass M and radius R initially stands vertically on the right end of a horizontal plank of mass M and length L, as shown in the figure. The plank rests on smooth horizontal floor and friction between disc and plank is sufficiently high such that disc rolls on plank without slipping. The plank is pulled to right with a constant horizontal force of magnitude F.



4. The magnitude of acceleration of plank is

(A) $\frac{F}{8M}$ (B) $\frac{F}{4M}$ (C) $\frac{3F}{2M}$ (D) $\frac{3F}{4M}$

5. The magnitude of angular acceleration of the disc is -

(A) $\frac{F}{4mR}$ (B) $\frac{F}{8mR}$ (C) $\frac{F}{2mR}$ (D) $\frac{3F}{2mR}$

6. The distance travelled by centre of disc from its initial position till the left end of plank comes vertically below the centre of disc is

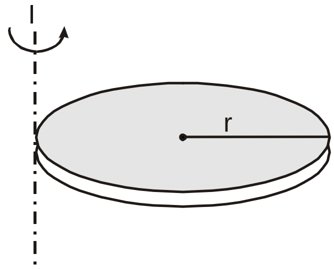
(A) $\frac{L}{2}$ (B) $\frac{L}{4}$ (C) $\frac{L}{8}$ (D) L

Exercise-3

Marked Questions can be used as Revision Questions.
*** Marked Questions may have more than one correct option.**

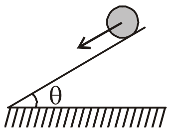
PART - I : JEE (ADVANCED) / IIT-JEE PROBLEMS (PREVIOUS YEARS)

1. A solid sphere of radius R has moment of inertia I about its geometrical axis. If it is melted into a disc of radius r and thickness t. If it's moment of inertia about the tangential axis (which is perpendicular to plane of the disc), is also equal to I, then the value of r is equal to : **[JEE 2006, 3/184]**



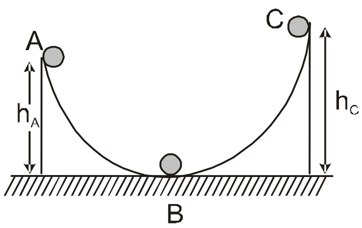
(A) $\frac{2}{\sqrt{15}}R$ (B) $\frac{2}{\sqrt{5}}R$ (C) $\frac{3}{\sqrt{15}}R$ (D) $\frac{\sqrt{3}}{\sqrt{15}}R$

2.* A solid sphere is in pure rolling motion on an inclined surface having inclination θ. **[JEE 2006, 5/184]**



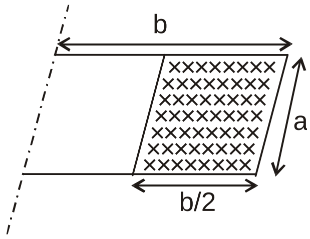
(A) frictional force acting on sphere is $f = \mu$ mg cos θ.
(B) f is dissipative force.
(C) friction will increase its angular velocity and decreases its linear velocity.
(D) If θ decreases, friction will decrease.

3*. A ball moves over a fixed track as shown in the figure. From A to B the ball rolls without slipping. If surface BC is frictionless and K_A, K_B and K_C are kinetic energies of the ball at A, B and C respectively, then : **[JEE 2006, 5/184]**



(A) $h_A > h_C$; $K_B > K_C$ (B) $h_A > h_C$; $K_C > K_A$ (C) $h_A = h_C$; $K_B = K_C$ (D) $h_A < h_C$; $K_B > K_C$

4. A rectangular plate of mass M of dimensions (a × b) is hinged along one edge. The plate is maintained in horizontal position by colliding a ball of mass m, per unit area, elastically 100 times per second this ball is striking on the right half shaded region of the plate as shown in figure. Find the required speed of the ball (ball is colliding in only half part of the plate as shown). (It is given M = 3 kg, m = 0.01 kg, b = 2 m, a = 1 m, g = 10 m/s^2) **[JEE 2006, 6/184]**



Paragraph for Question Nos. 5 to 7

Two discs A and B are mounted coaxially on a vertical axle. The discs have moments of inertia I and 2I respectively about the common axis. Disc A is imparted an initial angular velocity 2ω using the entire potential energy of a spring compressed by a distance x_1. Disc B is imparted an angular velocity ω by a spring having the same spring constant and compressed by a distance x_2. Both the discs rotate in the clockwise direction. **[JEE-2007, 12/162]**

5. The ratio x_1/x_2 is

(A) 2 (B) $\frac{1}{2}$ (C) $\sqrt{2}$ (D) $\frac{1}{\sqrt{2}}$

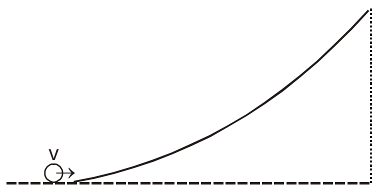
6. When disc B is brought in contact with disc A, they acquire a common angular velocity in time t. The average frictional torque on one disc by the other during this period is

(A) $\frac{2I\omega}{3t}$ (B) $\frac{9I\omega}{2t}$ (C) $\frac{9I\omega}{4t}$ (D) $\frac{3I\omega}{2t}$

7. The loss of kinetic energy during the above process is

(A) $\frac{I\omega^2}{2}$ (B) $\frac{I\omega^2}{3}$ (C) $\frac{I\omega^2}{4}$ (D) $\frac{I\omega^2}{6}$

8. A small object of uniform density rolls up a curved surface with an initial velocity v. It reaches up to a maximum height of $\frac{3v^2}{4g}$ with respect to the initial position. The object is **[JEE-2007, 3/162]**



(A) ring (B) solid sphere (C) hollow sphere (D) disc

9. **STATEMENT-1 :** If there is no external torque on a body about its centre of mass, then the velocity of the center of mass remains constant. **[JEE-2007, 3/162]**

because

STATEMENT-2 : The linear momentum of an isolated system remains constant.

(A) Statement-1 is True, Statement-2 is True; Statement-2 **is** a correct explanation for Statement-1

(B) Statement-1 is True, Statement-2 is True; Statement-2 **is NOT** a correct explanation for Statement1

(C) Statement-1 is True, Statement-2 is False

(D) Statement-1 is False, Statement-2 is True

10. **STATEMENT-1 :** Two cylinders, one hollow (metal) and the other solid (wood) with the same mass and identical dimensions are simultaneously allowed to roll without slipping down an inclined plane from the same height. The hollow cylinder will reach the bottom of the inclined plane first. **[JEE-2008, 3/163]**

and

STATEMENT-2 : By the principle of conservation of energy, the total kinetic energies of both the cylinders are identical when they reach the bottom of the incline.

(A) STATEMENT-1 is True, STATEMENT-2 is True; STATEMENT-2 is a correct explanation for STATEMENT-1

(B) STATEMENT-1 is True, STATEMENT-2 is True; STATEMENT-2 is NOT a correct explanation for

STATEMENT-1

(C) STATEMENT-1 is True, STATEMENT-2 is False

(D) STATEMENT-1 is False, STATEMENT-2 is True.

11. If the resultant of all the external forces acting on a system of particles is zero, then from an inertial frame, one can surely say that **[JEE 2009, 4/160, –1]**

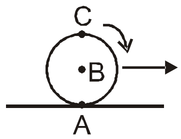
(A) linear momentum of the system does not change in time

(B) kinetic energy of the system does not changes in time

(C) angular momentum of the system does not change in time

(D) potential energy of the system does not change in time

12*. A sphere is rolling without slipping on a fixed horizontal plane surface. In the figure, A is the point of contact, B is the centre of the sphere and C is its topmost point. Then, **[JEE 2009, 4/160, –1]**



(A) $\vec{V}_C - \vec{V}_A = 2\left(\vec{V}_B - \vec{V}_C\right)$

(B) $\vec{V}_C - \vec{V}_B = \vec{V}_B - \vec{V}_A$

(C) $\left|\vec{V}_C - \vec{V}_A\right| = 2\ \left|\vec{V}_B - \vec{V}_C\right|$

(D) $\left|\vec{V}_C - \vec{V}_A\right| = 4\ \left|\vec{V}_B\right|$

13. A block of base 10 cm × 10 cm and height 15 cm is kept on an inclined plane. The coefficient of friction between them is $\sqrt{3}$. The inclination θ of this inclined plane from the horizontal plane is gradually increased from 0º. Then **[JEE 2009, 3/160, –1]**

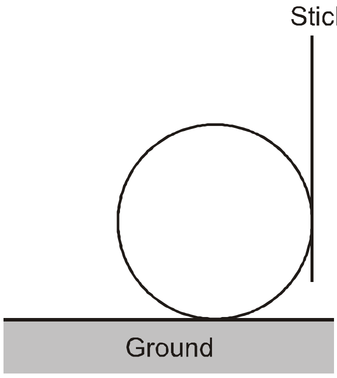
(A) at θ = 30º, the block will start sliding down the plane

(B) the block will remain at rest on the plane up to certain θ and then it will topple

(C) at θ = 60º, the block will start sliding down the plane and continue to do so at higher angles

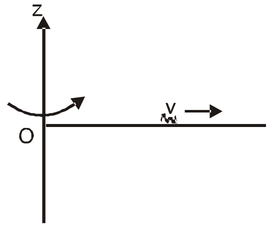
(D) at θ = 60º, the block will start sliding down the plane and on further increasing θ, it will topple at certain θ

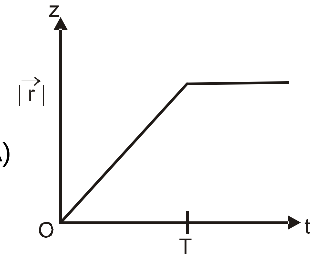
14. A boy is pushing a ring of mass 2 kg and radius 0.5 m with a vertical stick as shown in the figure. The stick applies a normal force of 2 N on the ring and rolls it without slipping with an acceleration of 0.3 m/s^2. The coefficient of friction between the ground and the ring is large enough that rolling always occurs and the coefficient of friction between the stick and the ring is (P/10). The value of P is **[JEE 2011, 4/160]**

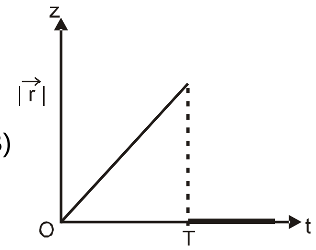


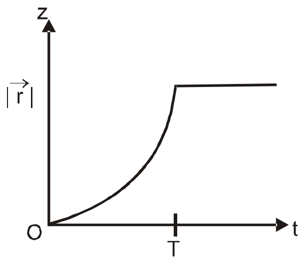
15. Four solid spheres each of diameter $\sqrt{5}$ cm and mass 0.5 kg are placed with their centers at the corners of a square of side 4cm. The moment of inertia of the system about the diagonal of the square is N × 10^{-4} kg-m^2, then N is **[JEE 2011, 4/160]**

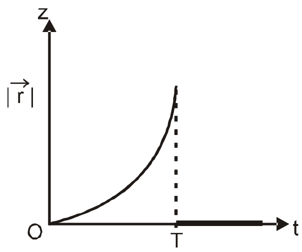
16. A thin uniform rod, pivoted at O, is rotating in the horizontal plane with constant angular speed ω, as shown in the figure. At time, t = 0, a small insect starts from O and moves with constant speed v with respect to the rod towards the other end. It reaches the end of the rod at t = T and stops. The angular speed of the system remains ω throughout. The magnitude of the torque ($|\vec{\tau}|$) on the system about O, as a function of time is best represented by which plot ? **[IIT-JEE-2012, Paper-1; 3/70, –1]**



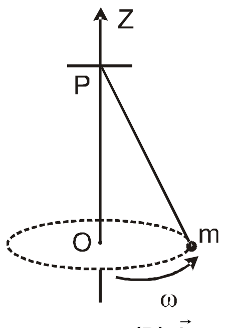
(A) 

(B) 

(C) 

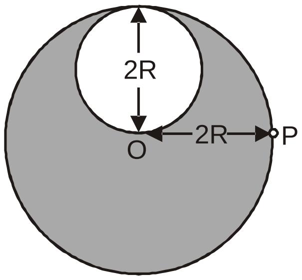
(D) 

17. A small mass m is attached to a massless string whose other end is fixed at P as shown in the figure. The mass is undergoing circular motion is the x-y plane with centre at O and constant angular speed ω. If the angular momentum of the system, calculated about O and P are denoted $\vec{L}_O$ by $\vec{L}_P$ and respectively, then **[IIT-JEE-2012, Paper-1; 3/70, –1]**



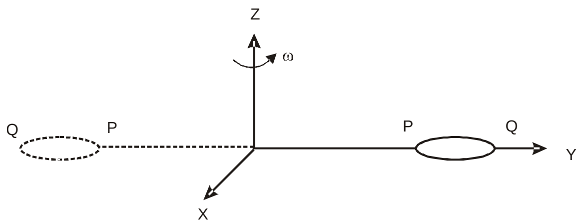
(A) $\vec{L}_O$ and $\vec{L}_P$ do not vary with time.
(B) $\vec{L}_O$ varies with time while $\vec{L}_P$ remains constant.
(C) $\vec{L}_O$ remains constant while $\vec{L}_P$ varies with time.
(D) $\vec{L}_O$ and $\vec{L}_P$ both vary with time.

18. A lamina is made by removing a small disc of diameter 2R from a bigger disc of uniform mass density and radius 2R, as shown in the figure. The moment of inertia of this lamina about axes passing through O and P is I_O and I_P, respectively. Both these axes are perpendicular to the plane of the lamina. The ratio $\frac{I_P}{I_O}$ to the nearest integer is : **[IIT-JEE-2012, Paper-1; 4/70]**

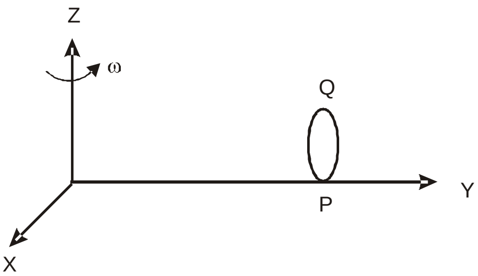


Paragraph for Q. No. 19-20

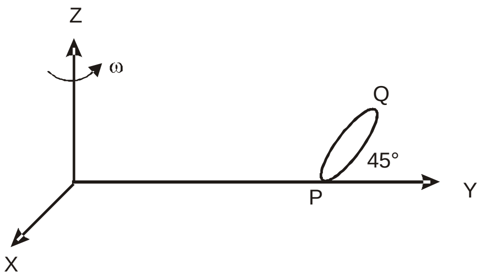
The general motion of a rigid body can be considered to be a combination of (i) a motion of its centre of mass about an axis, and (ii) its motion about an instantanneous axis passing through center of mass. These axes need not be stationary. Consider, for example, a thin uniform welded (rigidly fixed) horizontally at its rim to a massless stick, as shown in the figure. Where disc-stick system is rotated about the origin ona horizontal frictionless plane with angular speed ω, the motion at any instant can be taken as a combination of (i) a rotation of the centre of mass the disc about the z-axis, and (ii) a rotation of the disc through an instantaneous vertical axis passing through its centre of mass (as is seen from the changed orientation of points P and Q). Both the motions have the same angular speed ω in the case.



Now consider two similar systems as shown in the figure: case (a) the disc with its face vertical and parallel to x-z plane; Case (b) the disc with its face making an angle of 45° with x-y plane its horizontal diameter parallel to x-axis. In both the cases, the disc is welded at point P, and systems are rotated with constant angular speed ω about the z-axis.



Case (a)



Case (b)

19. Which of the following statement regarding the angular speed about the istantaneous axis (passing through the centre of mass) is correct? **[IIT-JEE-2012, Paper-2; 3/66, –1]**

(A) It is $\sqrt{2}\omega$ for both the cases

(B) it is ω for case (a); and $\frac{\omega}{\sqrt{2}}$ for case (b).

(C) It is ω for case (a); and $\sqrt{2}\omega$ for case (b)

(D) It is ω for both the cases

20. Which of the following statements about the instantaneous axis (passing through the centre of mass) is correct? **[IIT-JEE-2012, Paper-2; 3/66, –1]**

(A) It is vertical for both the cases (a) and (b).
(B) It is verticle for case (a); and is at 45° to the x-z plane and lies in the plane of the disc for case (b)
(C) It is horizontal ofr case (a); and is at 45° to the x-z plane and is normal to the plane of the disc for case (b).

(D) It is vertical of case (a); and is at 45° to the x - z plane and is normal to the plane of the disc for case (b).

21. Two solid cylinders P and Q of same mass and same radius start rolling down a fixed inclined plane form the same height at the same time. Cylinder P has most of its mass concentrated near its surface, while Q has most of its mass concentrated near the axis. Which statement (s) is (are) correct?

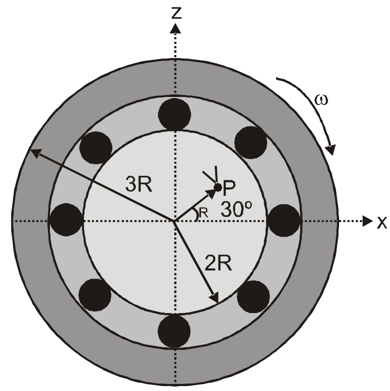
(A) Both cylinders P and Q reach the ground at the same time **[IIT-JEE-2012, Paper-2; 4/66]**

(B) Cylinder P has larger linear acceleration than cylinder Q.

(C) Both cylinder reaches the ground with same translational kinetic energy.

(D) Cylinder Q reaches the ground with larger angular speed.

22.* The figure shows a system consisting of (i) a ring of outer radius 3R rolling clockwise without slipping on a horizontal surface with angular speed ω and (ii) an inner disc of radius 2R rotating anti-clockwise with angular speed $\omega/2$. The ring and disc are separated frictionaless ball bearings. The system is in the x-z plane. The point P on the inner disc is at distance R from the origin O, where OP makes an angle of 30º with the horizontal. Then with respect to the horizontal surface, **[IIT-JEE-2012, Paper-2; 4/66]**



(A) the point O has linear velocity $3R\omega\,\hat{i}$.

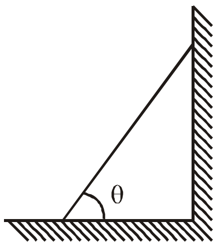
(B) the point P has a linear velocity $\frac{11}{4}R\omega\,\hat{i} + \frac{\sqrt{3}}{4}R\omega\,\hat{k}$

(C) the point P has linear velocity $\frac{13}{4}Rw\,\hat{i} - \frac{\sqrt{3}}{4}R\omega\,\hat{k}$

(D) The point P has a linear velocity $\left(3-\frac{\sqrt{3}}{4}\right)Rw\,\hat{i} + \frac{1}{4}Rw\,\hat{k}$.

23. A uniform circular disc of mass 50kg and radius 0.4 m is rotating with an angular velocity of 10 rad/s^{-1} about its own axis, which is vertical. Two uniform circular rings, each of mass 6.25 kg and radius 0.2 m, are gently placed symmetrically on the disc in such a manner that they are touching each other along the axis of the disc and are horizontal. Assume that the friction is large enough such that the rings are at rest relative to the disc and the system rotates about the original axis. The new angular velocity (in rad s^{-1}) of the system is : **[JEE (Advanced) 2013; 4/60]**

24.* In the figure, a ladder of mass m is shown leaning against a wall. It is in static equilibrium making an angle θ with the horizontal floor. The coefficient of friction between the wall and the ladder is μ_1 and that between the floor and the ladder is μ_2. The normal reaction of the wall on the ladder is N_1 and that of the floor is N_2. If the ladder is about to slip, then **[JEE (Advanced) 2014, P-1, 3/60]**



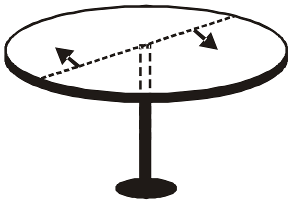
(A) $\mu_1 = 0$ $\mu_2 \neq 0$ and $N_2 \tan\theta = \frac{mg}{2}$

(B) $\mu_1 \neq 0$ $\mu_2 = 0$ and $N_1 \tan\theta = \frac{mg}{2}$

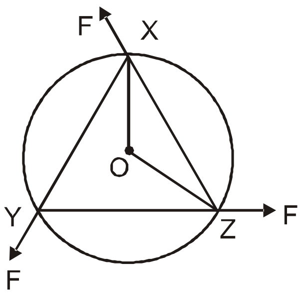
(C) $\mu_1 \neq 0$ $\mu_2 \neq 0$ and $N_2 = \frac{mg}{1+\mu_1\mu_2}$

(D) $\mu_1 = 0$ $\mu_2 \neq 0$ and $N_1 \tan\theta = \frac{mg}{2}$

25. A horizontal circular platform of radius 0.5 m and mass 0.45 kg is free to rotate about its axis. Two massless spring toy-guns, each carrying a steel ball of mass 0.05 kg are attached to the platfrom at a distance 0.25 m from the centre on its either sides along its diameter (see figure).Each gun simultaneously fires the balls horizontally and perpendicular to the diameter in opposite directions. After leaving the platfrom, the balls have horizontal speed of $9ms^{-1}$ with respect to the ground. The rotational speed of the platfrom in rad^{-1} after the balls leave the platform is **[JEE (Advanced)-2014,P-1, 3/60]**

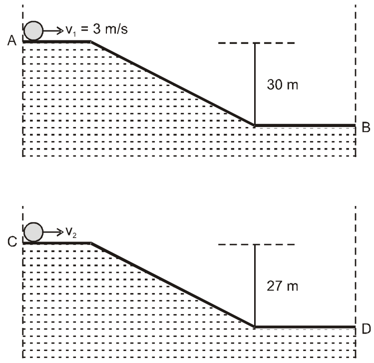


26. A uniform circular disc of mass 1.5 kg and radius 0.5m is initially at rest on a horizontal frictionless surface. Three forces of equal magnitude F = 0.5 N are applied simultaneously along the three sides of an equilateral triangle XYZ its vertices on the perimeter of the disc (see figure). One second after applying the forces, the angular speed of the disc in rad s^{-1} is : **[JEE (Advanced)-2014,P-1, 3/60]**

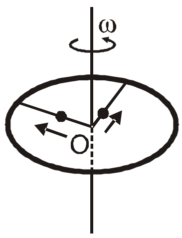


27. Two identical uniform discs roll without slipping on two different surfaces AB and CD (see figure) starting at A and C with linear speeds v_1 and v_2, respectively, and always remain in contact with ths surfaces. If they reach B and D with the same linear speed and v_1 = 3 m/s, then v_2 in m/s is (g = 10 m/s^2)

[JEE(Advanced) 2015 ; P-1, 4/88]



28. A ring of mass M and radius R is rotating with angular speed ω about a fixed vertical axis passing through its centre O with two point masses each of mass M/8 at rest at O. These masses can move radially outwards along two massless rods fixed on the ring as shown in the figure. At some instant the angular speed of the system is $8/9\omega$ and one of the masses is ata distance of $\frac{3}{5}R$ from O. At this instant the distance of the other mass from O is :



[JEE(Advanced) 2015 ; P-1, 4/88, –2]

(A) $\frac{2}{3}R$ (B) $\frac{1}{3}R$ (C) $\frac{3}{5}R$ (D) $\frac{4}{5}R$

29. The dinsities of two solid spheres A and B of the same radii R vary with radial distance r as $\rho_A(r) = k\left(\frac{r}{R}\right)$ and $\rho_B(r) = k\left(\frac{r}{R}\right)^5$, respectively, where k is a contant. The moments of inertia of the individual spheres about axes passing through their centres are I_A and I_B, respectively, If $\frac{I_B}{I_A} = \frac{n}{10}$, the value of n is : **[JEE(Advanced) 2015 ; P-2,4/88]**

30. A uniform wooden stick of mass 1.6 kg and length ℓ rests in an inclined manner on a smooth, vertical wall of height *h* (< ℓ) such that a small portion of the stick extends beyond the wall. The reaction force of the wall on the stick is perpendicular to the stick. The stick makes an angle of 30° with the wall and the bottom of the stick is on a rough floor. The reaction of the wall on the stick is equal in magnitude to the reaction of the floor on the stick. The ratio h/ℓ and the frictional force *f* at the bottom of the stick are (g = 10 ms^{-2}) **[JEE (Advanced) 2016 ; P-1, 3/62, –1]**

(A) $\frac{h}{l} = \frac{\sqrt{3}}{16}, f = \frac{16\sqrt{3}}{3}N$ (B) $\frac{h}{l} = \frac{3}{16}, f = \frac{16\sqrt{3}}{3}N$ (C) $\frac{h}{l} = \frac{3\sqrt{3}}{16}, f = \frac{8\sqrt{3}}{3}N$ (D) $\frac{h}{l} = \frac{3\sqrt{3}}{16}, f = \frac{16\sqrt{3}}{3}N$

31.* The position vector $\vec{r}$ of particle of mass m is given by the following equation $\vec{r}(t) = \alpha t^3\hat{i} + \beta t^2\hat{j}$
Where α = 10/3 m s^{-3}, β = 5 m s^{-2} and m = 0.1 kg. At t = 1 s, which of the following statement(s) is (are) true about the particle. **[JEE (Advanced) 2016 ; P-1, 4/62, –2]**

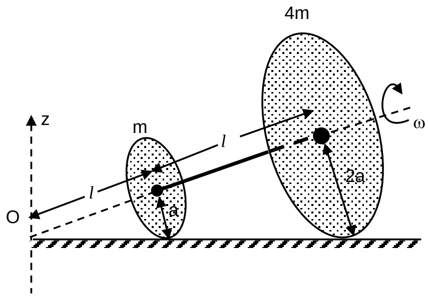
(A) The velocity $\vec{v}$ is given by $\vec{v} = (10\hat{i} + 10\hat{j})ms^{-1}$

(B) The angular momentum $\vec{L}$ with respect to the origin is given by $\vec{L} = -(5/3)\hat{k}$ N ms

(C) The force $\vec{F}$ is given by $\vec{F} = (\hat{i} + 2\hat{j})$ N

(D) The torque $\vec{\tau}$ with respect to the origin is given by $\vec{\tau} = -\frac{20}{3}\hat{k}$ Nm.

32.* Two thin circular discs of mass m and 4m, having radii of a and 2a, respectively, are rigidly fixed by a massless, rigid rod of length $l = \sqrt{24}a$ through their centers. This assembly is laid on a firm and flat surface, and set rolling without slipping on the surface so that the angular speed about the axis of the rod is ω. The angular momentum of the entire assembly about the point 'O' is $\vec{L}$ (see the figure). Which of the following statement (s) is (are) true ?



(A) The magnitude of the z-component of $\vec{L}$ is 55 ma^2 ω. **[JEE (Advanced) 2016 ; P-2, 4/62, –2]**

(B) The magnitude of angular momentum of the assembly about its centre of mass is 17 ma^2 $\frac{\omega}{2}$.

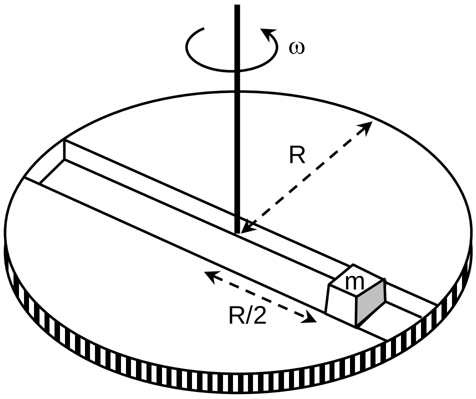
(C) The magnitude of angular momentum of centre of mass of the assembly about the point O is 81ma$^2\omega$.

(D) The centre of mass of the assembly rotates about the z-axis with an angular speed of ω/5.

Paragraph for Question Nos. 33 to 34

A frame of reference that is accelerated with respect to an inertial frame of reference is called a non-inertial frame of reference. A coordinate system fixed on a circular disc rotating about a fixed axis with a constant angular velocity ω is an example of a non-inertial frame of reference. The relationship between the force $\vec{F}_{rot}$ experienced by a particle of mass m moving on the rotating disc and the force $\vec{F}_{in}$ experienced by the particle in an inertial frame of reference is, $\vec{F}_{rot} = \vec{F}_{in} + 2m(\vec{v}_{rot} \times \vec{\omega}) + m(\vec{\omega} \times \vec{r}) \times \vec{\omega}$, Where $\vec{v}_{rot}$ is the velocity of the particle in the rotating frame of reference and $\vec{r}$ is the position vector of the particle with respect to the centre of the disc.

Now consider a smooth slot along a diameter of a disc of radius R rotating counter-clockwise with a constant angular speed ω about its vertical axis through its center. We assign a coordinate system with the origin at the center of the disc, the x-axis along the slot, the y-axis perpendicular to the slot and the z-axis along the rotation axis $\left(\vec{\omega} = \omega\hat{k}\right)$. A small block of mass m is gently placed in the slot at $\vec{r} = (R/2)\hat{i}$ at t = 0 and is constrained to move only along the slot.



33. The distance r of the block at time t is **[JEE (Advanced) 2016 ; P-2, 3/62, –1]**

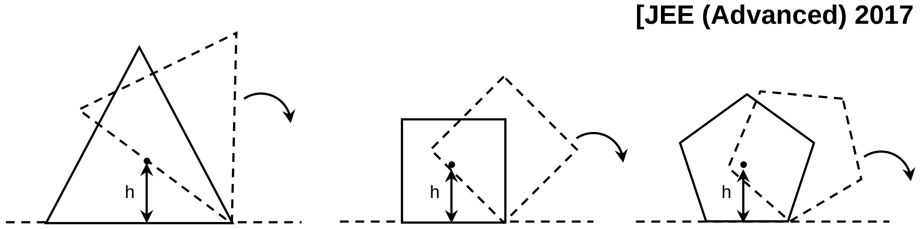
(A) $\frac{R}{2}\cos 2\omega t$ (B) $\frac{R}{4}\left(e^{2\omega t} + e^{-2\omega t}\right)$ (C) $\frac{R}{2}\cos\omega t$ (D) $\frac{R}{4}\left(e^{\omega t} + e^{-\omega t}\right)$

34. The net reaction of the disc on the block is : **[JEE (Advanced) 2016 ; P-2, 3/62, –1]**

(A) $m\omega^2 R\sin\omega t\,\hat{j} - mg\hat{k}$ (B) $-m\omega^2 R\cos\omega t\,\hat{j} - mg\hat{k}$

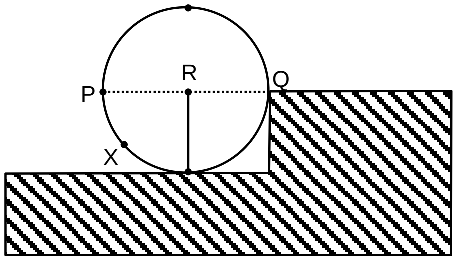
(C) $\frac{1}{2}m\omega^2 R\left(e^{\omega t} - e^{-\omega t}\right)\hat{j} + mg\hat{k}$ (D) $\frac{1}{2}m\omega^2 R\left(e^{2\omega t} - e^{-2\omega t}\right)\hat{j} + mg\hat{k}$

35. Consider regular polygons with number of sides n = 3, 4, 5 .... as shown in the figure. The centre of mass of all the polygons is at height h from the ground. They roll on a horizontal surface about the leading vertex without slipping and sliding as depicted. The maximum increase in height of the locus of the center of mass for each polygon is Δ. Then Δ depends on n and h as **[JEE (Advanced) 2017 ; P-2, 3/61, –1]**



(A) $\Delta = h\sin\left(\frac{2\pi}{n}\right)$ (B) $\Delta = h\tan^2\left(\frac{\pi}{2n}\right)$ (C) $\Delta = h\sin^2\left(\frac{\pi}{n}\right)$ (D) $\Delta = h\left(\frac{1}{\cos\left(\frac{\pi}{n}\right)} - 1\right)$

36. A wheel of radius R and mass M is placed at the bottom of a fixed step of height R as shown in the figure. A constant force is continuously applied on the surface of the wheel so that it just climbs the step without slipping. Consider the torque τ about an axis normal to the plane of the paper passing through the point Q. Which of the following options is/are correct ? **[JEE (Advanced) 2017 ; P-2, 4/61, –2]**



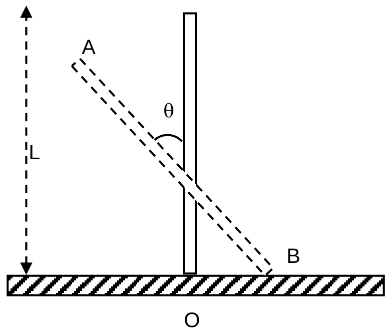
(A) If the force is applied normal to the circumference at point P then τ is zero

(B) If the force is applied tangentially at point S then $\tau \neq 0$ but the wheel never climbs the step

(C) If the force is applied at point P tangentially then τ decreases continuously as the wheel climbs

(D) If the force is applied normal to the circumference at point X then τ is constant

37.* A rigid uniform bar AB of length L is slipping from its vertical position on a frictionless floor (as shown in the figure). At some instant of time, the angle made by the bar with the vertical is θ. Which of the following statements about its motion is/are correct ? **[JEE (Advanced) 2017 ; P-2, 4/61, –2]**



(A) The trajectory of the point A is a parabola
(B) Instantaneous torque about the point in contact with the floor is proportional to sin θ.
(C) When the bar makes an angle θ with the vertical, the displacement of its midpoint from the initial position is proportional to (1– cosθ)
(D) The midpoint of the bar will fall vertically downward.

Paragraph for Question Nos. 38 to 39

One twirls a circular ring (of mass M and radius R) near the tip of one's finger as shown in Figure-1. In the process the finger never loses contact with the inner rim of the ring. The finger traces out the surface of a cone, shown by the dotted line. The radius of the path traced out by the point where the ring and the finger is in contact is r. The finger rotates with an angular velocity ω_0. The rotating ring *rolls without slipping* on the outside of a smaller circle described by the point where the ring and the finger is in contact (Figure-2).

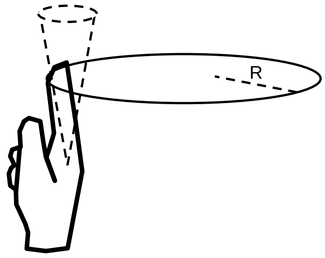


Figure-1

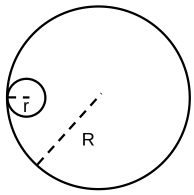


Figure-2

The coefficient of friction between the ring and the finger is μ and the acceleration due to gravity is g.

38. The total kinetic energy of the ring is : **[JEE (Advanced) 2017 ; P-2, 3/61]**

(A) $\frac{1}{2}M\omega_0^2(R-r)^2$ (B) $\frac{3}{2}M\omega_0^2(R-r)^2$ (C) $M\omega_0^2R^2$ (D) $M\omega_0^2(R-r)^2$

39. The minimum value of ω_0 below which the ring will drop down is : **[JEE (Advanced) 2017 ; P-2, 3/61]**

(A) $\sqrt{\frac{g}{\mu(R-r)}}$ (B) $\sqrt{\frac{g}{2\mu(R-r)}}$ (C) $\sqrt{\frac{3g}{2\mu(R-r)}}$ (D) $\sqrt{\frac{2g}{\mu(R-r)}}$

40*. Consider a body of mass 1.0 kg at rest at the origin at time t = 0. A force $\vec{F}=(\alpha t\hat{i}+\beta\hat{j})$ is applied on the body, where α = 1.0 Ns^{-1} and β = 1.0 N. The torque acting on the body about the origin at time t = 1.0s is $\vec{\tau}$. Which of the following statements is (are) true? **[JEE (Advanced) 2018 ; P-1, 4/60]**

(A) $|\tau|=\frac{1}{3}$Nm

(B) The torque $\vec{\tau}$ is in the direction of the unit vector $+\hat{k}$

(C) The velocity of the body at t = 1 s is $\vec{v}=\frac{1}{2}(\hat{i}+2\hat{j})ms^{-1}$

(D) The magnitude of displacement of the body at t = 1 s is $\frac{1}{6}$m

41. A ring and a disc are initially at rest, side by side, at the top of an inclined plane which makes an angle 60° with the horizontal. They start to roll without slipping at the same instant of time along the shortest path. If the time difference between their reaching the ground is $(2-\sqrt{3})/\sqrt{10}$ s, then the height of the top of the inclined plane, in metres, is __________. Take g = 10 ms^{-2}. **[JEE (Advanced) 2018 ; P-1, 3/60]**

42. In the List-I below, four different paths of a particle are given as functions of time. In these functions, α and β are positive constants of appropriate dimensions and $\alpha \neq \beta$. In each case, the force acting on the particle is either zero or conservative. In List-II, five physical quantities of the particle are mentioned:

$\vec{p}$ is the linear momentum, $\vec{L}$ is the angular momentum about the origin, K is the kinetic energy, U is the potential energy and E is the total energy. Match each path in List-I with those quantities in List-II, which are **conserved for that path**. **[JEE (Advanced) 2018 ; P-2, 3/60, –1]**

List-I		**List-II**	
P.	$\vec{r}(t) = \alpha t\hat{i} + \beta t\hat{j}$	1.	$\vec{p}$
Q.	$\vec{r}(t) = \alpha \cos\omega t\hat{i} + \beta \sin\omega t\hat{j}$	2.	$\vec{L}$
R.	$\vec{r}(t) = \alpha(\cos\omega t\hat{i} + \sin\omega t\hat{j})$	3.	K
S.	$\vec{r}(t) = \alpha t\hat{i} + \frac{\beta}{2}t^2\hat{j}$	4.	U
		5.	E

(A) P → 1, 2, 3, 4, 5; Q → 2, 5; R → 2, 3, 4, 5; S → 5
(B) P → 1, 2, 3, 4, 5; Q → 3, 5; R → 2, 3, 4, 5; S → 2, 5
(C) P → 2, 3, 4; Q → 5; R → 1, 2, 4; S → 2, 5
(D) P → 1, 2, 3, 5; Q → 2, 5; R →2, 3, 4, 5; S → 2, 5

PART - II : JEE (MAIN) / AIEEE PROBLEMS (PREVIOUS YEARS)

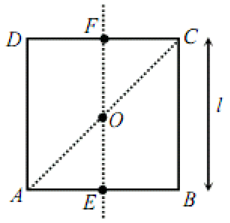
1. A thin circular ring of mass m and radius R is rotating about its axis with a constant angular velocity ω. Two objects each of mass M are attached gently to the opposite ends of a diameter of the ring. The ring now rotates with an angular velocity ω' : **[AIEEE-2006, 4½/180]**

(1) $\frac{\omega m}{(m+2M)}$ (2) $\frac{\omega(m+2M)}{m}$ (3) $\frac{\omega(m-2M)}{(m+2M)}$ (4) $\frac{\omega m}{(m+M)}$

2. Four point masses, each of value m, are placed at the corners of a square ABCD of side □. The moment of inertia about an axis passing through A and parallel to BD is : **[AIEEE-2006, 4½/180]**

(1) m□^{2} (2) 2m□^{2} (3) $\sqrt{3}$ m□^{2} (4) 3m□^{2}

3. For the given uniform square lamina ABCD, whose centre is O, **[AIEEE 2007, 3/120]**



(1) $\sqrt{2}I_{AC} = I_{EF}$ (2) $I_{AD} = 2I_{EF}$ (3) $I_{AC} = I_{EF}$ (4) $I_{AC} = \sqrt{2}I_{EF}$

4. A round uniform body of radius R, mass M and moment of inertia I rolls down (without slipping) an inclined plane making an angle θ ? With the horizontal. Then its acceleration is : **[AIEEE 3/120 2007]**

(1) $\frac{g\sin\theta}{1+I/MR^2}$ (2) $\frac{g\sin\theta}{1+MR^2/I}$ (3) $\frac{g\sin\theta}{1-I/MR^2}$ (4) $\frac{g\sin\theta}{1-MR^2/I}$

5. Angular momentum of the particle rotating with a central force is constant due to : **[AIEEE 3/120 2007]**

(1) constant force (2) constant linear momentum
(3) zero torque (4) constant torque

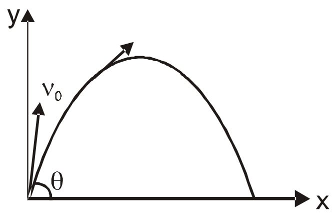
6. Consider a uniform square plate of side 'a' and mass 'm'. The moment of inertia of this plate about an axis perpendicular to its plane and passing through one of its corners is : **[AIEEE 3/105 2008]**

(1) $\frac{1}{12}ma^2$ (2) $\frac{7}{12}ma^2$ (3) $\frac{2}{3}ma^2$ (4) $\frac{5}{6}ma^2$

7. A thin uniform rod of length □ and mass m is swinging freely about a horizontal axis passing through its end. Its maximum angular speed is ω. Its centre of mass rises to a maximum height of :
[AIEEE 4/144 2009]

(1) $\frac{1}{6}\frac{\ell\omega}{g}$ (2) $\frac{1}{2}\frac{\ell^2\omega^2}{g}$ (3) $\frac{1}{6}\frac{\ell^2\omega^2}{g}$ (4) $\frac{1}{3}\frac{\ell^2\omega^2}{g}$

8. A small particle of mass m is projected at an angle θ with the x-axis with an initial velocity v_0 in the x-y plane as shown in the figure. At a time $t < \frac{v_0 \sin\theta}{g}$, the angular momentum of the particle is **[AIEEE 4/144 2010]**



(1) $-mg\, v_0\, t^2 \cos\theta\, \hat{j}$ (2) $mg\, v_0\, t \cos\theta\, \hat{k}$

(3) $-\frac{1}{2}\, mg\, v_0\, t^2 \cos\theta\, \hat{k}$ (4) $\frac{1}{2} mg\, v_0\, t^2 \cos\theta\, \hat{i}$

where $\hat{i}$, $\hat{j}$ and $\hat{k}$ are unit vectors along x, y and z-axis respectively.

9. A thin horizontal circular disc is rotating about a vertical axis passing through its centre. An insect is at rest at a point near the rim of the disc. The insect now moves along a diameter of the disc to reach its other end. During the journey of the insect, the angular speed of the disc : **[AIEEE - 2011, 4/120, –1]**

(1) remains unchanged (2) continuously decreases
(3) continuously increases (4) first increases and then decreases

10. A mass m hangs with the help of a string wrapped around a pulley on a frictionless bearing. The pulley has mass m and radius R. Assuming pulley to be a perfect uniform circular disc, the acceleration of the mass m, if the string does not slip on the pulley, is : **[AIEEE - 2011, 4/120, –1]**

(1) $\frac{3}{2}g$ (2) g (3) $\frac{2}{3}g$ (4) $\frac{g}{3}$

11. A pulley of radius 2m is rotated about its axis by a force F = $(20t - 5t^2)$ newton (where t is measured in seconds) applied tangentially. If the moment of inertia of the pulley about its axis of rotation is 10 kg m^2, the number of rotations made by the pulley before its direction of motion if reversed, is :**[AIEEE - 2011, 4/120, –1]**

(1) less than 3 (2) more than 3 but less than 6
(3) more than 6 but less than 9 (4) more than 9

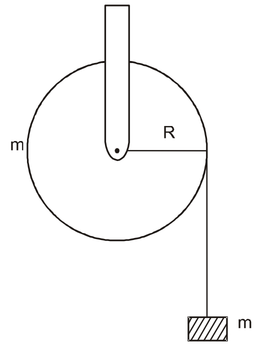
12. A particle of mass 'm' is projected with a velocity υ making an angle of 30^o with the horizontal. The magnitude of angular momentum of the projectile about the point of projection when the particle is at its maximum height 'h' is : **[AIEEE 2011, 11 May; 4/120, –1]**

(1) zero (2) $\frac{m\upsilon^3}{\sqrt{2}g}$ (3) $\frac{\sqrt{3}}{16}\frac{m\upsilon^3}{g}$ (4) $\frac{\sqrt{3}}{2}\frac{m\upsilon^2}{g}$

13. A hoop of radius r and mass m rotating with an angular velocity ω_0 is placed on a rough horizontal surface. The initial velocity of the centre of the hoop is zero. What will be the velocity of the centre of the hoop when it ceases to slip ? **[AIEEE 2013, 4/120, –1]**

(1) $\frac{r\omega_0}{4}$ (2) $\frac{r\omega_0}{3}$ (3) $\frac{r\omega_0}{2}$ (4) $r\omega_0$

14. A mass 'm' supported by a massless string wound around a uniform hollow cylinder of mass m and radius R. If the string does not slip on the cylinder, with what acceleration will the mass fall on release ? **[JEE (Main) 2014, 4/120, –1]**



(1) $\frac{2g}{3}$ (2) $\frac{g}{2}$ (3) $\frac{5g}{6}$ (4) g

15. A bob of mass m attached to an inextensible string of length *l* is suspended from a vertical support. The bob rotates in a horizontal circle with a angular speed ω rad/s about the vertical. About the point of suspension : **[JEE (Main) 2014, 4/120, –1]**

(1) angular momentum is conserved.
(2) angular momentum changes in magnitude but not in direction

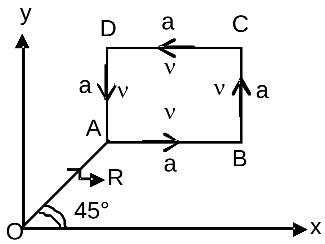
(3) angular momentum changes in direction but not in magnitude.
(4) angular momentum changes both in direction and magnitude.

16. Form a solid sphere of mass M and radius R a cube of maximum possible volume is cut. Moment of inertia of cube about an axis passing through its centre and perpendicular to one of its faces is

[JEE (Main)-2015; 4/120, –1]

(1) $\frac{MR^2}{32\sqrt{2}\pi}$ (2) $\frac{MR^2}{16\sqrt{2}\pi}$ (3) $\frac{4MR^2}{9\sqrt{3}\pi}$ (4) $\frac{4MR^2}{3\sqrt{3}\pi}$

17. A particle of mass m is moving along the side of square of side 'a' with a uniform speed ν in the x-y plane as shown in the figure :



Which of the following statements is false for the angular momentum about the origin ?

(1) $\vec{L} = m\nu\left[\frac{R}{\sqrt{2}} - a\right]\hat{k}$ when the particle is moving from C to D.

(2) $\vec{L} = m\nu\left[\frac{R}{\sqrt{2}} + a\right]\hat{k}$ when the particle is moving from B to C.

(3) $\vec{L} = \frac{m\nu}{\sqrt{2}}R\ \hat{k}$ when the particle is moving from D to A.

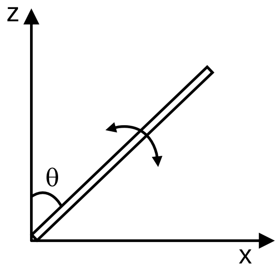
(4) $\vec{L} = -\frac{m\nu}{\sqrt{2}}R\ \hat{k}$ when the particle is moving from A to B.

18. The moment of inertia of a uniform cylinder of length l and radius R about its perpendicular bisector is I. What is the ratio l/R such that the moment of inertia is minimum ? **[JEE (Main) 2017 ; 4/120, –1]**

(1) $\frac{3}{\sqrt{2}}$ (2) $\sqrt{\frac{3}{2}}$ (3) $\frac{\sqrt{3}}{2}$ (4) 1

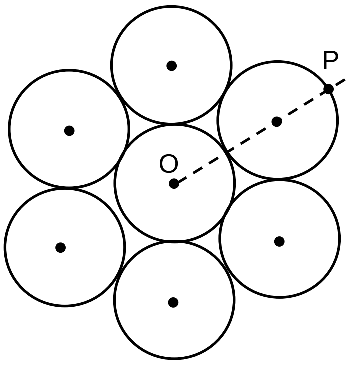
19. A slender uniform rod of mass M and length l is pivoted at one end so that it can rotate in a vertical plane (see figure). There is negligible friction at the pivot. The free end is held vertically above the pivot and then released. The angular acceleration of the rod when it makes an angle θ with the vertical is.

[JEE (Main) 2017; 4/120, –1]



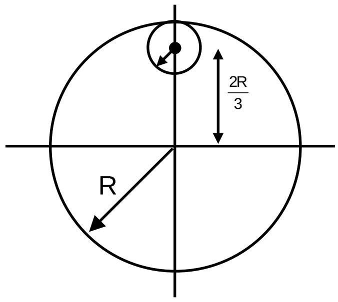
(1) $\frac{2g}{3l}\cos\theta$ (2) $\frac{3g}{2l}\sin\theta$ (3) $\frac{2g}{3l}\sin\theta$ (4) $\frac{3g}{2l}\cos\theta$

20. Seven identical circular planar disks, each of mass M and radius R are welded symmetrically as shown. The moment of inertia of the arrangement about the axis normal to the plane and passing through the point P is : **[JEE (Main) 2018; 4/120, –1]**



(1) $\frac{73}{2}MR^2$ (2) $\frac{181}{2}MR^2$ (3) $\frac{19}{2}MR^2$ (4) $\frac{55}{2}MR^2$

21. From a uniform circular disc of radius R and mass 9 M, a small disc of radius $\frac{R}{3}$ is removed as shown in the figure. The moment of inertia of the remaining disc about an axis perpendicular to the plane of the disc and passing through centre of disc is : **[JEE (Main) 2018; 4/120, –1]**



(1) $10\ MR^2$ (2) $\frac{37}{9}MR^2$ (3) $4\ MR^2$ (4) $\frac{40}{9}MR^2$

Answers

EXERCISE-1

PART - I

Section (A) :

A-1. $4\ rev/s^2$, 20 rev/s **A-2.** 20 s

Section (B) :

B-1. $\frac{ML^2}{12}$ **B-2.** $\frac{M\ell^2}{6}$

B-3. $\frac{MR^2}{2} - M\left(\frac{4R}{3\pi}\right)^2$ **B-4.** $(K = \sqrt{\frac{3}{2}}\, r)$

Section (C) :

C-1. $-14\hat{i} + 10\hat{j} - 9\hat{k}$

C-2. $mg\ell \sin\theta$, when the bob is at the lowest point, at $\theta = 90^o$.

C-3. (a) $mv^2 \sin\alpha \cos\alpha$ perpendicular to the plane of motion
(b) $2mv^2 \sin\alpha \cos\alpha$ perpendicular to the plane of motion

C-4. 3N – m

Section (D) :

D-1. 2.4 N in the left string and 2.6 N in the right

D-2. $P = \frac{w}{2}\cot\theta$ or $P = \frac{mg}{2}\cot\theta$

D-3. 990 N, 960 N, $\frac{32}{33}$

D-4. (i) T = 250 N (ii) F_H= 150 N (→), F_V= 50 N (↑)

Section (E) :

E-1. (a) $\frac{2g}{\ell}\frac{(m_1-m_2)}{(m_1+m_2)} = \frac{10}{3}\ rad/s^2$

(b) (i) $\alpha' = \frac{2(m_1-m_2)g}{\ell\left[m_1+m_2+\frac{m_3}{3}\right]} = 3\ rad/s^2$,

(ii) 42 N ; 39 N

E-2. (a) $\frac{3g}{4L}$ (cw)

(b) $N = \frac{13\ mg}{16}\uparrow$, $F = \left(\frac{3\sqrt{3}}{16}\right)mg \rightarrow$

E-3. $3\ rad/s^2$

E-4. $N = F\left(1-\frac{3}{2}\frac{x}{\ell}\right)$

Section (F) :

F-1. $\omega = \sqrt{5}$ rad/s **F-2.** $\omega = \sqrt{\frac{9\ g}{4\ \ell}}$

F-3. $\frac{1}{2}m\omega^2\left(R^2+\frac{L^2}{12}\right)$ **F-4.** 2 m/s

Section (G) :

G-1. $2\hat{k}\ kg\ m^2/s$ **G-2.** $16\ kg\ m^2/s$

G-3. $\frac{\left(I+\frac{mr^2}{2}\right)\omega_0}{I+2mr^2}$ **G-4.** 10 rad/s

G-5. $\frac{4\pi m}{M+2m}$ **G-6.** $3v / 4\ell$

Section (H) :

H-1 V_A = 25 m/s , V_B = 75 m/s

H-2 V_O = 4 m/sec $\hat{i}$, $V_A = (4\hat{i} + 3\hat{j})$m/sec

H-3 V_{CM} = 7 m/s.

H-4 (a) $\frac{4v_0}{3}$ (b) $\frac{5v_0}{3\ell}$

(c) $v_x = \frac{v_0}{2}$, $v_y = -\frac{2v_0}{3}$

H-5. (a) v_A = 2at = 10.0 cm/s,
$v_B = \sqrt{2}$ at = 7.1 cm/s, v_0 = 0 ;

(b) $a_A = 2a\sqrt{1+\left(\frac{2t^2a}{R}\right)^2} = 5.6\ cm/s^2$,

$a_B = a = 2.5\ cm/s^2$, $a_0 = a^2t^2 / R = 2.5\ cm/s^2$

Section (I) :

I-1. $\sqrt{\frac{4gh}{3}}$ **I-2.** $\frac{7}{10}mv^2$

I-3. $\frac{2}{3}g$ **I-4.** $\frac{7}{3}mg$

I-5. $\sqrt{3g(R-r)}$ **I-6.** $4\pi R/5$

I-7. $5\ \mu mg$, 20 N

Section (J) :

J-1. $\omega = 3\ v/2$□

J-2. (a) $\frac{m_2u}{m_1+m_2}$ (b) $\frac{m_1u}{m_1+m_2}$

(c) $-\frac{m_2u}{m_1+m_2}$

(d) $\frac{m_1^2m_2uL}{2(m_1+m_2)^2}, \frac{m_1m_2^2uL}{2\ \ (m_1+m_2)^2}$

(e) $\frac{m_1(m_1+4m_2)L^2}{12\ \ (m_1+m_2)}$

(f) $\frac{m_2u}{m_1+m_2}, \frac{6m_2u}{(m_1+4m_2)L}$

J-3. (a) $\frac{I}{m}, \frac{2I}{mR}$ (b) $\frac{\pi mR}{2I}$ (c) $\frac{\pi R}{2}$

J-4. 100 rad/sec.

Section (K) :

K-1. $\frac{1}{2}mg\ a\sin\theta$, $x = \frac{a\tan\theta}{2}$

PART - II

Section (A) :

A-1. (B) **A-2.** (C)

Section (B) :

B-1. (C) **B-2.** (A) **B-3.** (A)
B-4. (C) **B-5.** (D) **B-6.** (C)
B-7. (C) **B-8.** (B) **B-9.** (D)
B-10. (D) **B-11.** (D)

Section (C) :

C-1. (A) **C-2.** (C) **C-3.** (C)

Section (D) :

D-1. (B) **D-2.** (C) **D-3** (B)
D-4 (A) **D-5.** (C)

Section (E) :

E-1. (A) **E-2.** (C) **E-3.** (D)
E-4. (A) **E-5.** (C)

Section (F) :

F-1. (B) **F-2.** (C)

Section (G) :

G-1. (C) **G-2.** (B) **G-3.** (D)
G-4. (B) **G-5.** (C)

Section (H) :

H-1. (B) **H-2.** (B) **H-3.** (C)
H-4. (A) **H-5.** (A)

Section (I) :

I-1. (B) **I-2.** (A) **I-3.** (B)
I-4. (D) **I-5.** (A) **I-6.** (D)
I-7. (A) **I-8.** (C) **I-9.** (D)

Section (J) :

J-1. (D) **J-2.** (B)

Section (K) :

K-1. (A) **K-2.** (A) **K-3.** (A)

PART - III

1. (A) $\rightarrow$p,q,r ; (B) $\rightarrow$ p,q,r ; (C)$\rightarrow$p,q;(D) $\rightarrow$p,q,r
2. (A) $\rightarrow$ p ; (B) $\rightarrow$ q, s;(C) $\rightarrow$p ;(D) $\rightarrow$q, s

EXERCISE-2

PART - I

1.	(D)	**2.**	(D)	**3.**	(D)
4.	(C)	**5.**	(C)	**6.**	(B)
7.	(D)	**8.**	(B)	**9.**	(B)
10.	(D)	**11.**	(D)	**12.**	(B)
13.	(C)	**14.**	(A)	**15.**	(D)
16.	(A)	**17.**	(A)	**18.**	(D)
19.	(B)	**20.**	(B)	**21.**	(B)
22.	(D)	**23.**	(B)	**24.**	(A)

PART - II

1.	16	**2.**	28	**3.**	2
4.	6	**5.**	2	**6.**	4
7.	4	**8.**	10	**9.**	1
10.	2	**11.**	8	**12.**	9
13.	5	**14.**	1	**15.**	2
16.	10	**17.**	(a) 10	(b) 20	
18.	25	**19.**	12	**20.**	20
21.	9	**22.**	5		

PART - III

1.	(CD)	**2.**	(ABC)	**3.**	(ABC)
4.	(ABCD)	**5.**	(ACD)	**6.**	(BC)
7.	(ABC)	**8.**	(ACD)	**9.**	(CD)
10.	(ABCD)	**11.**	(BC)	**12.**	(ABD)
13.	(ABC)	**14.**	(BC)	**15.**	(ACD)
16.	(AD)	**17.**	(ACD)		

PART - IV

1.	(B)	**2.**	(C)	**3.**	(D)
4.	(D)	**5.**	(C)	**6.**	(A)

EXERCISE-3

PART - I

1.	(A)	**2.**	(CD)	**3.**	(AB)
4.	10	**5.**	(C)	**6.**	(A)

7.	(B)	**8.**	(D)	**9.**	(D)
10.	(D)	**11.**	(A)	**12.**	(BC)
13.	(B)	**14.**	4	**15.**	9
16.	(B)	**17.**	(C)	**18.**	3
19.	(D)	**20.**	(A)	**21.**	(D)
22.	(AB)	**23.**	8	**24.**	(CD)
25.	4	**26.**	2	**27.**	7
28.	(D)	**29.**	6	**30.**	(D)
30.	(D)	**31.**	(ABD)	**32.**	(D)
33.	(D)	**34.**	(C)	**35.**	(D)
36.	(A)	**37.**	(BCD)	**38.**	(Bonus)
39.	(A)	**40.**	(AC)	**41.**	0.75
42.	(A)				

PART - II

1.	(1)	**2.**	(4)	**3.**	(3)
4.	(1)	**5.**	(3)	**6.**	(3)
7.	(3)	**8.**	(3)	**9.**	(4)
10.	(3)	**11.**	(2)	**12.**	(3)
13.	(3)	**14.**	(2)	**15.**	(3)
16.	(3)	**17.**	(1,3)	**18.**	(2)
19.	(2)	**20.**	(2)	**21.**	(3)