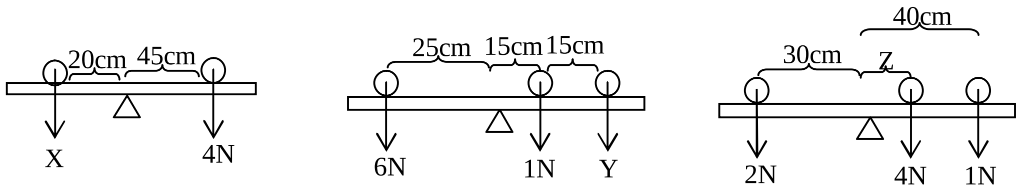
Mechanics

Rotational Motion, Circular motion, Centre of mass & gravity

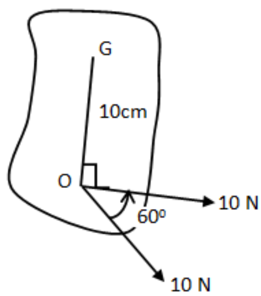
01. Calculator the size of these couples,

02. The uniform meter rulers of weight 1kg in the diagrams are balanced. Find the missing values of X, Y and the reaction on supporting wedge.

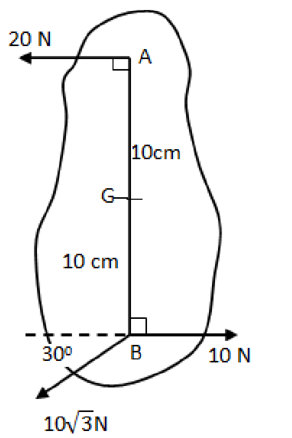
03. The diagrams show rulers balanced at their canters of gravity. What are the missing values of X, Y & Z? What are reaction forces acting on supporting wedge?



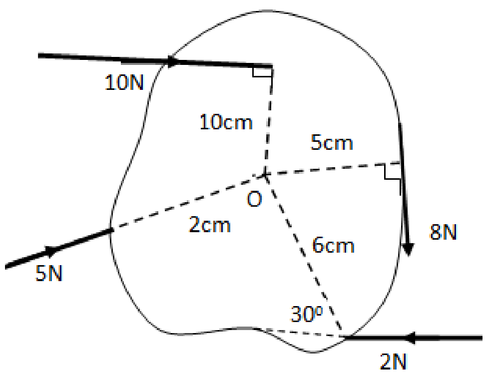
04. Find the moment about the O. what is the size of perpendicular force and its direction acting on point O in order bring the system in equilibrium?



05. Consider the following diagram.
    I. Find the moment of force about G, A and B.
    II. Where is the place on AB line of 40 N perpendicular force applied in order to bring the system in equilibrium about G, A and B.

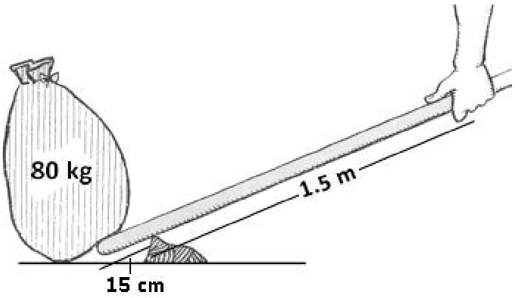


06. Find the moment of force about O point.

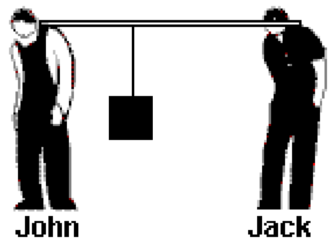


M.A.Shafi
B.Sc (Hons.) Phy.Sp

07. A man uses a pole to shift a sack of scrap iron with mass 80 kg. He uses a stone as fulcrum, the stone being 15 cm from the bag, as shown in the above sketch. What minimum force must he apply at a point 1.5 m from the fulcrum in order to move the sack?



08. John and Jack carry a 100 kg mass hanging from a pole of negligible mass, each end of which rests on the shoulders of one of the two men. The pole is 2.4 m long, and the load is 0.6 m nearer John than it is to Jack. The weights of the john and jack are 80 kg and 60 kg respectively. If both are moving on a rough horizontal surface of coefficient of dynamic friction 0.5 with speed $5ms^{-1}$. Find the force excreted by the each person themselves.



09. A rod 60 cm long whose weight may be neglected is supposed horizontally on two knife edges at the ends and a mass 12kg is suspended from the rod at a distance of 40 cm from the one end. Find the reaction due to each support of knife.

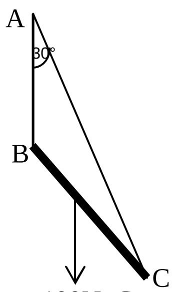
10. Weights of 4kg and 6kg respectively are suspended from the ends. X and Y of a light rod of length 2m. Find the point in the rod at which the rod can be supported 6 N on a knife edge.

11. A uniform plank AB which is 6m long and has a weight of 300N supported horizontally by two vertical ropes at A and B. A weight of 150N rests on the plank at C where AC = 2m. Find the tension in each rope. (Ans: 200N, 250N)

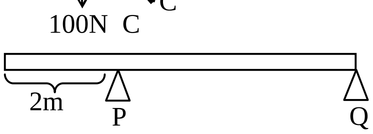
12. A uniform ladder which is 5m long and has a mass of 20 kg leans with its upper end against a smooth vertical wall and its lower end on rough ground. The bottom of the ladder is 3m from the wall. Calculate the frictional force between the ladder and the ground. (Ans: 75N)

13. A simple wooden bridge across a river is supported by two roads 4.8 m apart. The wooden plank is uniform and weight 100kg. A boy of mass 60kg stands on the wooden plank 1.5 m from left hand support. Find the reaction forces at the end of plank.

14. A particle of mass 10kg is suspended by two strings of lengths 8m and 6m attached to points 10m apart. Determine the tension in the string. (Ans: 60N, 80N)

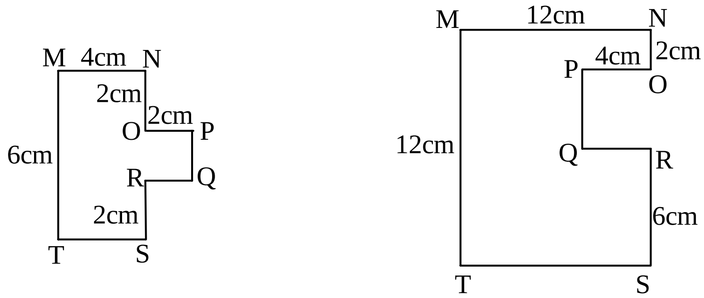
15. 

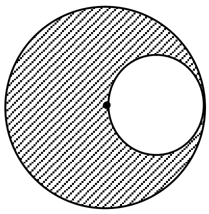
One end of uniform rod of mass 10kg is hinged smoothly at B and other end C is suspended by a light string at A. The string is $30°$ to the vertical and AB = BC = 2m. Find the tension in the string and the magnitude of the reaction at the hinge.

16. 

The length of a uniform rod of mass 50kg is 5m. The rod is held horizontally on the two knife edges P and Q, 3m apart. Determine how for a child of mass 40kg can warlk from Q comfortably.

17. Calculator the position of the centre of gravity of a body which comprises two small spheres whose centres are connected by a straight rod of length L and negligible mass. The masses of the spheres are m_1 & m_2.
18. Calculator the position of the centre of gravity of system of three particle each of mass m and located at the vertices of an equilateral triangle of side L.
19. MNOPQRST is a uniform lamina whose dimensions are shown in following figure. Find the distance of its centre of gravity from MN and from MT.



20. 

The mass uniform disc of radius R is m. The circular portion of diameter R is reamed from it. What is the centre of gravity of remain part of its centre.

21. A boy spin a bicycle wheel (diameter of 1 m, mass of 5 kg), applying a force of 25 N tangentially. find the angular acceleration, angular displacement, no of turns, average speed of the wheel in 10 s.
22. Radius of fly wheel of grinder is 10 cm and its rotating at 2400 revolution per minute. Find angular velocity, angular acceleration and centripetal acceleration of partial at circumference.
23. The wheels of a cycle (radius = 0.5m) are rotating rest with angular acceleration of $3rads^{-2}$. Find angular displacement, velocity, tangential velocity and centripetal acceleration after 20 s.
24. The disc of radius of 25cm is rotating about its axis through the centre from rest to 900 rpm in 10s. Find the angular acceleration tangential acceleration angular displacement and no of turn.
25. Flying wheel whose moment of inertial is $0.6\,kgm^2$ is held in a horizontal axel of radius 2cm. The mass of the axle is ignored when compared to the mass of the flying wheel. When a force of 90 N is applied tangentially to the axle find angular acceleration.
26. A dancer whose moment of inertia is $2kgm^2$ about the axis of rotation is rotating with her hands stretched at the role of 4 rotations per second. When hands are folded and the moment of inertia about the same axis is $1kgm^2$. Find the rate of rotation and increase of kinetic energy.
27. A wheel whose moment of inertia about its axis passing through the centre is $8kgm^2$ and rotating with angular velocity $60rads^1$ is brought to rest by a firm resistive torque in 20s. Find the torque.

28. A rotating grinding wheel of moment of inertia 5 $kg\ m^2$ and radius 1 m is rotated from 300 r.p.m to 900 r.p.m in 10 s by using an external tangential force applied on its circumference. Find (π^2 = 10)

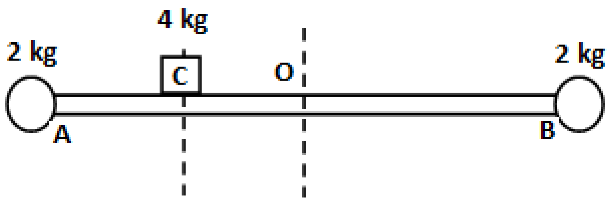
i) Find initial and final angular velocity after 10 s
ii) Angular acceleration,
iii) No of turns rotated in 10 s duration,
iv) Average angular speed,
v) Increase of kinetic energy,
vi) Tangential force,
vii) Work done by tangential in 10 s

29. The mass and radius of solid fly wheel disc is 1.6 kg and 50 cm respectively. It is rotated by a rope wound round the circumference of the wheel by a tangential force of 16N. Find the angular acceleration.

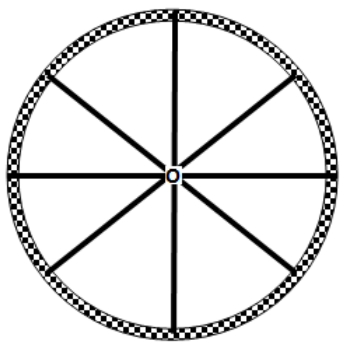
30. A & B are two masses of 2 kg each connected to the end of mass less rod of length 2 m. Find

i) Moment of inertia about centre of rod
ii) Moment of inertia about the one mass
iii) If the mass of rod is 12 kg. Find the moment of inertia about the centre and one end of rod.

31. The objects of A and B of mass 2 kg each are attached to the uniform rod AB of mass 12 kg and length 4 m as shown in the figure. Another object of C of mass 4 kg is attached on the rod 1 m from the object A. find the moment of inertia about O, A, B and C.



32. Four uniform rods of each mass 6 kg and length 2 m are attached to a ring of mass 12 kg and diameter 2 m.



a. Find the angular momentum of the system when it's rotated clockwise direction with angular speed 5 $rad\ s^{-1}$ about centre of the ring O.
b. If another uniform ring of mass 20 kg and diameter 2 m is placed smoothly on the rotating system, find the new angular velocity of the system.
c. If another uniform ring of mass 20 kg and radius 1 m is rotated clockwise direction with speed 2.5 $rad\ s^{-1}$ is placed smoothly on the centre of ring in (a) and finally they are rotates with common angular speed ω_1. Find ω_1 .
d. If another uniform ring of mass 10 kg and radius 1 m is rotated anticlockwise direction with speed 1 $rad\ s^{-1}$ is placed smoothly on the centre of ring in (a) and finally they are rotates with common angular speed ω_2. Find ω_2 .

33. A wheel rerates at an angular velocity of $20rads^1$ about an axis passing through its centre. The moment of inertial of the wheel about the axis is $6kgm^2$. If a tongue of 30 Nm can bring the wheel to rest. Find the number of turns.

34. A wheel whose moment of inertia is $0.6kgm^1$ and diameter 6cm supported on a horizontal axis if a force 80 N applied

a) Tangentially
b) at $60°$ to the tangent

Find the angular acceleration & angular velocity after 30 s if wheel start at rest.

35. An experimenting student stands at the centre of a freely rotating turntable, holding his arms horizontally with 10kg mass in each hand. The angular velocity of the turntable is $4rads^1$. When the distance of each weight from the axis of rotation is 1.0m and moment of inertia of student turntable is$10kgm^2$. When student fold his hands to his side and hold them firmly so that each weight is now 0.25m away from. Find the axis and moment of inertia of turntable and student is $8.75kgm^2$.

i) New angular velocity of the system.
ii) Change of mechanical energy
iii) Work done by the student to fold his hands.
iv) Force applied on each masses by the student.

36. The diameter, moment of inertia and initial angular velocity of merry-go – round is 4m, $1800kgm^2$ and $8rads^{-1}$ respectively when four boys of mass 37.5 kg each. Sit on the circumference of merry-go-round. Find angular velocity of system immediately after boys sit on. When boys run at a speed of $5ms^{-1}$ along the tangent of its rim and humps on. Find the angular velocity of system immediately after jumped on?

37. The diameter and mass of the wheel is 1 m and 2 kg respectively. Its moment of inertia about its axis of rotation is $2\ kg\ m^2$. The wheel is moving on a horizontal surface without slipping at 7 revolution per second. Calculate:

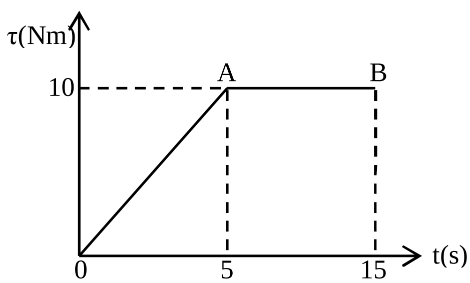
a) The angular velocity in $rads^{-1}$
b) The linear velocity of the centre of
c) The instantaneous linear velocity of the topmost point and lower point on the wheel.
d) The total energy of the wheel.

38. A wheel whose moment of inertia about an axis through its centre is $8\ kg\ m^2$. It is rotating with an angular velocity $20\ rad\ s^{-1}$ and is brought to rest in 8 s by the application of a torque.

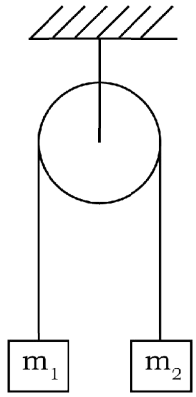
Find:

1) Angular deceleration
2) Torque applied on it
3) If radius of the wheel is 0.6m. Find distance travelled by an particle which is at circumference on the wheel.
4) Work done by torque.

39. A variable torque with time is applied on disk of moment of inertia $5kgm^2$ as show above graph it disc starting with $10rads^{-1}$, Find:



i) Angular velocity at A point
ii) Angular velocity at B point
iii) Angular acceleration in AB period
iv) Work done by Torque at to = 6 s to = 15 s

40. 

The objects of mass m_1 & m_2 are connected by a two ends of a inelastic mass less string and its go over a pulley of moment of inertia I and radius r. If pulley and system will rotates without slipping.

a. Find the tension of string / strings, acceleration of the each objects and tension in the string.

b. If m_1= 5 kg, m_2 = 3 kg, I = 12 $kg\, m^2$ and r = 1 m, find the tensions of strings.

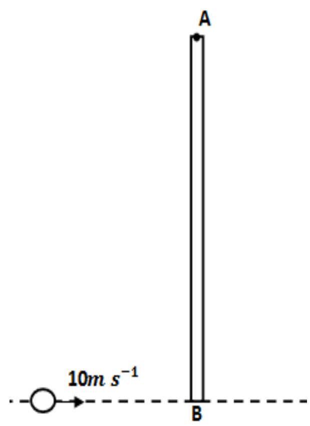
41. The mass and the time period of the Earth is M & T respectively. An asteroid of mass m is fallen on the equator of the Earth. Assume the Earth is solid sphere, show that the change of the time period (ΔT) of the earth is

$$\Delta T = \frac{5\, m\, T}{2\, M}$$

a. Find the new time period of the Earth when mass of the asteroid is 10 % of the Earth.

b. What is the mass of the asteroid fallen on the earth in order double the time period of the earth?

42. Uniform rod AB of length 1 m and mass 12 kg is pivoted smoothly about A. An object of mass 1 kg is moving with speed 10 $m\, s^{-1}$ along the horizontal line passing through the point B as shown in figure. Find the angular speed of the rod just after impact for following cases.



a) After impact the object is firmly attached with rod.

b) After impact the object moves the 5$m\, s^{-1}$ to the same direction.

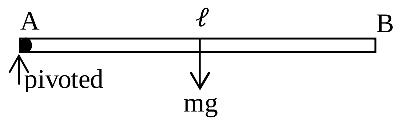
c) After impact the object bounces with the same speed.

d) After impact the object bounces with the speed 5$m\, s^{-1}$.

e) If the impact is elastic, find the speed of the object and angular speed of the rod.

f) If another object of mass 4 kg moves with the speed of 10$m\, s^{-1}$ along the horizontal line passing through the centre of the mass of the rod, find a),b),c),d) and e) separately.

43. Uniform rod of mass M and length ℓ is pivoted at end A and it keeps horizontally to rotated freely without friction. (See figure) Find :



a) Initial angular acceleration.

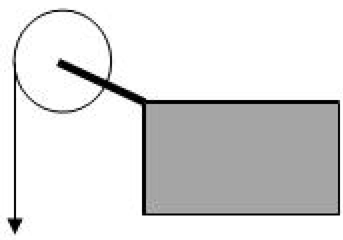
b) Tangential acceleration of the B end.

c) Angular velocity when rod its reached to vertical position

d) Tangential velocity of the B end when its reached to vertical position.

e) Draw graph of angular acceleration V_s angular displacement.

44. A uniform disc of mass M = 2kg and radius R=1 m is rotated without slipping vertically about its centre by rope wound round the circumference of disc applying a tangential force of T= 5N. Find the angular acceleration of the disc. Next, 4 kg of mass is attached to the free end of rope and release to move. Find the new angular acceleration, acceleration of mass 4kg & tension of rope.



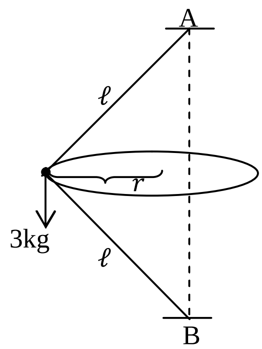
45. A chain of cycle connects two wheels A & B of diameter 25 cm and 8 cm respectively. When A rotates at $160 rav\, s^{-1}$ what is the angular velocity in $rav\, s^{-1}$? [Ans: 500 $rav\, s^{-1}$]

46. An object of mass 10kg tied to an inextensible string is rotated. Horizontal circle with angular velocity is $5 rads^{-1}$. The length of the string is 0.3m. Calculate the tension in the string.

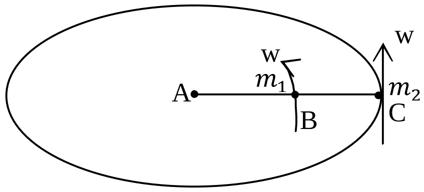
47. An object is moving at the rate of 70 revolutions per second in circle of radius 50 cm. Calculate
   i) Angular velocity
   ii) Its tangential speed
   iii) Time period

48. A mass of 40kg suspended from a fixed point O by a string of length 1m is rotating 1kg horizontal circle of radium 60cm at a constant speed. Calculate
   i) The tension in the string
   ii) Centripetal force on the mass
   iii) The period of the object in its orbit.

49. An object of mass 3kg tied one end of two strings of length 100cm. And the other two end of strings are suspended to two fixed points of AB = 160cm. The object is moving constant speed of $6 ms^{-1}$. Find the tension of each string.



50. Two objects of mass m_1 & m_2 m_1 is tied using two string s and m_2 is tied using only BC. Two mass are rotating with w $rads^{-1}$ about A axis. Find the ration of tension on tension AB / tension BC. If $m_1 = m_2$ and AB = BC. Find ration of tension AB/BC.



51. A racing car of 500kg moves round a banked track at a constant speed of $108 kmh^{-1}$. Assuming the total reaction at the wheels is normal to the track and the horizontal radius of track is $30\sqrt{3}$ m. Calculate the angle of inclination of the track to horizontal and the reaction at the wheel (Assume μ=0)

52. A boy is seated on top of a hemispherical mound of ice of radius 4R. He is given a little push and he starts sliding down the ice. If ice is frictionless the boy will leave the ice at a point height?

53. A vehicle of mass 1000kg is moving at a speed $20 ms^{-1}$ around a banked road of diameter 30 m. and coefficient of friction is 0.5. Find the maximum and minimum speed that vehicle moves without slipping on the road if the road is inclined to the horizontal $45°$ and radius remain constant. State your answer the vehicle can move safely or not safely on banked road with this speed.

1. A solid cylinder of mass M and radius R rolls down an inclined plane of height h. The angular velocity of the cylinder when it reaches the bottom of the plane will be

(1) $\frac{\sqrt{gh}}{2}$ (2) $\frac{2}{R}\sqrt{gh}$ (3) $\frac{2}{R}\sqrt{\frac{gh}{2}}$ (4) $\frac{2}{R}\sqrt{\frac{gh}{3}}$ (5) $\frac{1}{2R}\sqrt{gh}$

2. A light-weight boy holds two heavy dumb bells of equal mass with outstretched arms while standing on a turn table which is rotating at an angular frequency ω_1 when the dumb bells are at a distance r_1 from the axis of rotation. The boy suddenly pulls the dumb bells towards his chest until they are at a distance r_2 from the axis of rotation. The new angular frequency of rotation ω_2 of the turn table will be equal to

(1) $\omega_1\frac{r_2}{r_1}$ (2) $\omega_1\frac{r_1^2}{r_2^2}$ (3) $\omega_1\frac{r_1}{r_2}$ (4) $\omega_1\frac{r_2^2}{r_1^2}$ (5) $2\omega_1$

3. If the Earth were to suddenly contract to half its present size, without changing in its mass, the duration of the new day will be

(1) 3 hours (2) 6 hours (3) 12 hours (4) 18 hours (5) 30 hours

4. An object of mass 10% of earths were falls on the earths, the duration of the new day will be

(1) 3 hours (2) 6 hours (3) 12 hours (4) 18 hours (5) 30 hours

5. A solid sphere rolls down from the top of an inclined plane. Its velocity on reaching the bottom of the plane is V. when the same sphere slides down from the top of the plane, its velocity on reaching the bottom is V^1. Then ratio V^1 / V is

(1) $\sqrt{\frac{3}{5}}$ (2) 1 (3) 2 (4) $\sqrt{\frac{7}{5}}$ (5) $\frac{3}{\sqrt{5}}$

6. A circular disc rolls down an inclined plane without slipping. What fraction of its total energy is translational

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

7. A sphere rolls down an inclined plane without slipping. What fraction of its total energy is rotational?

(1) 2 / 7 (2) 3 / 7 (3) 4 / 7 (4) 5 / 7 (5) 6 / 7

8. Circular disc is rolling down an inclined plane without slipping. If the angle of inclination is 300, the acceleration of the disc down the inclined plane is

(1) g (2) g / 2 (3) g / 3 (4) $\sqrt{2}$ g / 3 (5) g / 4

9. A block of mass M is released from the top of an inclined plane. Its velocity on reaching the bottom of plane is U. A circular disc of the same mass M rolls down the incline plane from the top. Its velocity on reaching the bottom is V. the ratio V / U will be

(1) $1/\sqrt{3}$ (2) $\sqrt{2/3}$ (3) 1 (4) $2\sqrt{2}$ / 3 (5) 2

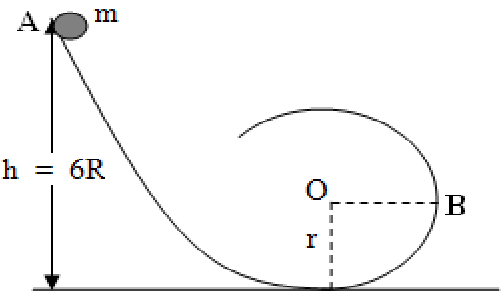
10. Two circular loops A and B of radii R and 2R respectively are made of the same wire. Their moments of inertia about the axis passing through the centre and perpendicular to their plane are I_A and I_B respectively. The ratio I_A / I_B is

(1) 1 (2) 1 / 2 (3) 1 / 4 (4) 1 / 8 (5) 2

11. A sphere of mass M and radius R is released from the top of an inclined plane of inclination θ. The minimum coefficient of friction between the plane and the sphere so that it rolls down the plane without sliding is given by

(1) $\mu = \tan\theta$ (2) $\mu = (2\tan\theta)/3$ (3) $\mu = (2\tan\theta)/5$
(4) $\mu = (2\tan\theta)/7$ (5) $\mu = (3\tan\theta)/5$

12. The track shown in figure end in a circular track of radius r with centre at O. A small solid sphere of mass m rolls from rest without slipping from a point A at a height h = 6R from the level ground. What is the speed of sphere when it reaches a point B at height r above the level ground?



(1) $\sqrt{gR}$ (2) $\sqrt{10gr}$ (3) $\sqrt{\frac{50}{7}gr}$

(4) $\sqrt{\frac{22}{7}gr}$ (5) zero

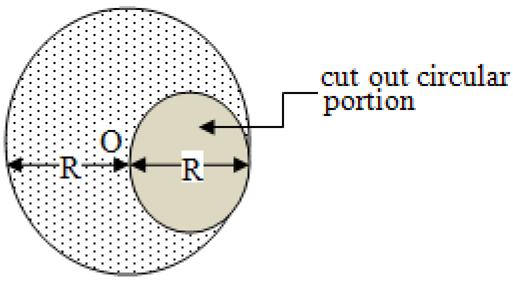
13. In Q.14 above, the horizontal force acting on the sphere when it reaches B is

(1) 10 mg (2) mg (3) 50 mg / 7 (4) 22 mg / 7 (5) 7 mg / 22

14. A circular disc of radius R is free to oscillate about an axis passing through a point on its rim and perpendicular to its plane. The disc is turned through an angle of 60^0 and released. Its angular velocity when it reaches the equilibrium position will be,

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

15. A circular portion of diameter R is cut out from a uniform circular disc of mass M and radius R as shown in figure. The moment of inertia of the remaining (shaded) portion of the disc about an axis passing through the centre O of the disc and perpendicular to its plane is



(1) $\frac{15}{32}MR^2$ (2) $\frac{7}{16}MR^2$ (3) $\frac{13}{32}MR^2$
(4) $\frac{3}{8}MR^2$ (5) $\frac{1}{8}MR^2$

16. The moment of inertia of a hollow sphere of mass M and internal and external radii R and 2R about an axis passing through its centre and perpendicular to its plane is

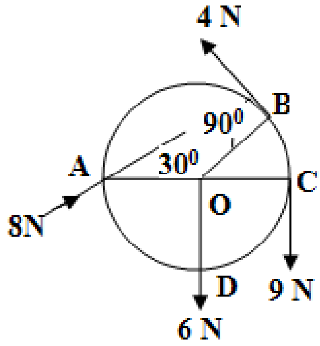
(1) $\frac{3}{2}MR^2$ (2) $\frac{13}{32}MR^2$ (3) $\frac{31}{35}MR^2$ (4) $\frac{35}{62}MR^2$ (5) $\frac{62}{35}MR^2$

17. A man standing on a turn-table, is rotating at a certain angular frequency with his arms out-stretched. He suddenly folds his arms. If his moment of inertia with folded arms is 75 % of that with outstretched arms, his rotational kinetic energy will

(1) increase by 33.3 % (2) decrease by 33.3 % (3) increase by 25%
(4) decrease by 25 % (5) increase by 66.6 %

18. Two blocks of masses 1 kg and 2 kg are suspended at the end of a light string passing over a frictionless pulley of mass 4 kg and radius 10 cm. when the masses are released, the acceleration of the system is

(1) g / 9 (2) g / 7 (3) g / 5 (4) g / 3 (5) g / 2



19. Four forces are applied to a wheel of radius 20 cm as show figure. The net torque produced by the forces is

(1) 5.4 Nm anticlockwise (2) 1.8 Nm clockwise
(3) 2.0 Nm clockwise (4) 5.4 Nm clockwise
(5) none of these

20. A hollow sphere of mass M and radius R is initially at rest on a horizontal rough surface. It moves under the action of a constant horizontal force F as shown figure. The linear acceleration of the sphere is

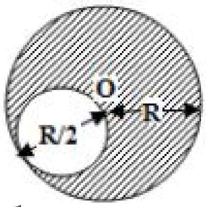
(1) $\frac{10F}{7M}$ **(2)** $\frac{5F}{7M}$ (3) $\frac{7F}{5M}$ (4) $\frac{6F}{5M}$ (5) $\frac{F}{m}$

21. In Q.22 the frictional force between the sphere and the surface is

(1) F / 2 (2) F / 3 (3) F / 4 (4) F / 5 (5) F / 6

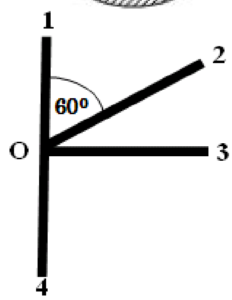
22. Two identical discs of mass M and radius R are joined. The gyration of system about an axis through their point(O) of constant and perpendicular to the plane

(1) $\sqrt{3}$R (2) $\sqrt{5}$ R (3) $\sqrt{7}$ R (5) $\sqrt{11/2R}$ (5) $\sqrt{2/7}$ R



23. A circular part taken off from a uniform disc of radius R as shown in figure If the mass of remaining disc is M then its moment of inertia about an axis through O and perpendicular to the plane of disc is

(1) $\frac{3}{24}MR^2$ (2) $\frac{13}{24}MR^2$ (3) $\frac{13}{32}MR^2$ (4) $\frac{16}{24}MR^2$ (5) $\frac{19}{24}MR^2$



24. A light rod is free to rotate about a horizontal axis through one of its end O. if due to a slight disturbance it falls under gravity, then at position 2, 3 and 4 its angular speeds respectively be ω_2, ω_3, ω_4. Consider the following statements

(a)$\omega_4 = 2\omega_2$ (b) $\omega_4 = 2\omega_3$ (c) $\omega_3 = 1.5\ \omega_2$ (d) $\omega_3 = \sqrt{2}\omega_2$

The correct statements are

(1) a and b only (2) b and c only (3) c and d only (4) d and a only (5) b and d only

25. A solid metallic sphere of radius R having moment of inertia equal to I about its diameter is melted and recast into a solid disc of radius r of a uniform thickness. The moment of inertia of the disc about an axis passing through its edge and perpendicular to its plane is also equal to I. the ratio r / R is

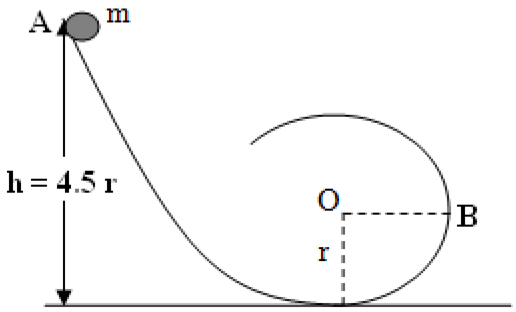
(1) $\frac{2}{\sqrt{15}}$ (2) $\frac{2}{\sqrt{10}}$ (3) $\frac{2}{\sqrt{5}}$ (4) $\frac{2}{\sqrt{5}}$ (5) $\frac{1}{\sqrt{2}}$

.

26. A uniform disc of mass M and radius R rolls without slipping down a plane inclined at angle θ with the horizontal. The frictional force act on the disc is

(1) Mg Sinθ / 3 (2) 2Mg Sinθ / 3 (3) Mg Sinθ (4) 4Mg Sinθ / 3 (5) none of these

27. A small solid sphere of mass m rolls without slipping on the track shown figure. The radius of the circular part of the track is r. the sphere starts from rest from point A at a height 4.5 r above the bottom. The magnitude of the force acting on the sphere when it is at point B is



(1) $\sqrt{4.5}$ mg (2) $\sqrt{5}$ mg (3) $\sqrt{26}$ mg
(4) $3\sqrt{3}$ mg (5) mg

28. A flywheel of mass 60 kg, radius 40 cm is revolving 300 revolutions per min. its kinetic energy will be

(1) $480\pi^2$J (2) 48 J (3) 48 π J (4) 4 / π J (5) 48 / π J

29. The angular velocity of a body changes from ω_1 to ω_2 without applying torque but by changing moment of inertia. The ratio of initial radius of gyration to the final radius of gyration is

(1) $\omega_2 : \omega_1$ (2) $\omega_2^2 : \omega_1^2$ (3) $\sqrt{\omega_2} : \sqrt{\omega_1}$ (4) $1/\omega_2 : 1/\omega_1$ (5) $1/\omega_2^2 : 1/\omega_1^2$