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# PHYSICS

# BOOKS - HC VERMA PHYSICS (ENGLISH)

# CIRCULAR MOTION

## Example

**1.** A article moves in a circle of radius 20 cm with linear speed of 10 m/s. Find the angular velocity

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**2.** A particle travels in a circle of radius 20 cm at a speed thast uniformly increases. If the speed changes from 5.0 m/s to 6.0 m/s in 2.0s, find the angular aceleration.

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**3.** Find the magnitude of the linear acceleration of a particle moving in a circle of radius 10 cm with uniform speed completing the circle in 4s.

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**4.** A particle moves in a circle of radius 20 cm. Its linear speed is given by v=2t, where t is in second and v in metre/ second. Find the radial and tangential acceleration at t=3s.

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**5.** A small block of mass 100 g moves wth uniform speed n a horizontal circular groove, with vertical side walls, of radisu 25 cm.If the block takes 2.0 s to complete ne round, find the normal contact force by tehside wall of the groove.

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**6.** The road at a circular turn of radius 10 m is banked by an angle of $10^0$. With what speed should a vehicle move on the turn so that the normal contact force is able to provide the necessary centripetal force?

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**7.** A body weights 98 N on a spring balance at the north pole. What will be its weight recorded on the same scale if it is shifted to te equator? Use g=$G\frac{M}{R^2} = 9.8\frac{m}{s^2}$ and the radius of the earth R=6400 km.

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## Worked Out Examples

**1.** A car has to move on a level turn of radius 45 m. If the coefficient of static friction between the tyre and the road is $\mu_s = 2.0$, find the maximum speed the car can take without skidding.

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**2.** A circular track of radius 600 m is tio be designed for cars at an average speed of 180 km/hr. What should be the angle of banking of the track?

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**3.** A particle of mass m is suspended from a ceiling through a string of length L. The particle moves in a horizontal circle of radius r.

Find a. the speed of the particle and b. the tension in the string. Such a system is called a conical pendulum.

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**4.** One end of a massless spring of spring constant 100 N/m and natural length 0.5 m is fixed and the other end is connected to a particle of mass 0.5 kg lying on as frictionless horizontal table. The spring remains horizontal. If the mass is made to rotate at an angular velocity of 2 rad/s, find the elongation of the spring.

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**5.** A simple pendulum is constructed by attaching a bob of mass m to a string of length L fixed at its upper end. The bob oscillates in a vertical circle. It is found that the speed of the bob is v when the string makes an angle $\theta$ with the vertical. Find the tension in the string at this instant.

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**6.** A cylindrical bucket filled with watert is whirled around in a vertical circle of radius r. What can be the minimum speed at the top of the path if water does not all out from the bucketgt? If it continues with this speed, what normal contact force the bucket exerts on water at teh lowest point of the path?

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**7.** A fighter plane is pulling out for a dive t a speed of 900 km/hr. Assuming its path to be a vertical circle of radius 2000 m and its mass to be 16000 kg, find the force exerted by tehair on it at the lowest point. Take $g = 9.8 \frac{m}{s^2}$.

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**8.** Figure shows as rod of length 20 cm pivoted near an end and which is made to rotate in a horizontal plane with a constant angular speed. A ball ofmass m is spuspended by a string angular also of length 20 cm from the other end of the rod. If the angle $\theta$ made by the stirng with the vertical is $30^0$. find the anglular speed of the rotation. Take $g = 10\frac{m}{s^2}$

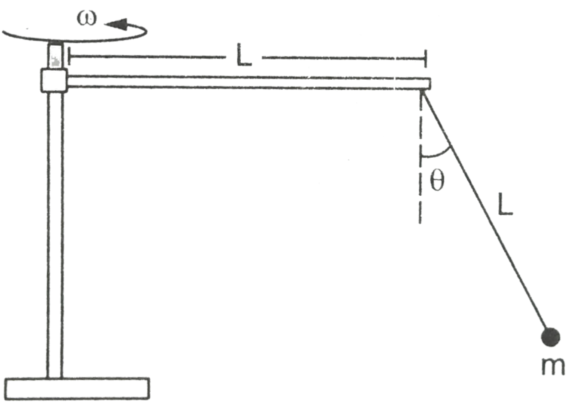


Figure 7-W5

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**9.** Two blocks each of mass M are connected to the ends of a light frame as shown in figure. The frame is rotated about the vertical line of symmetry. The rod breaks if the tension in it exceeds $T_0$. Find the maximum frequency with which the frame may be rotted without breaking the rod.

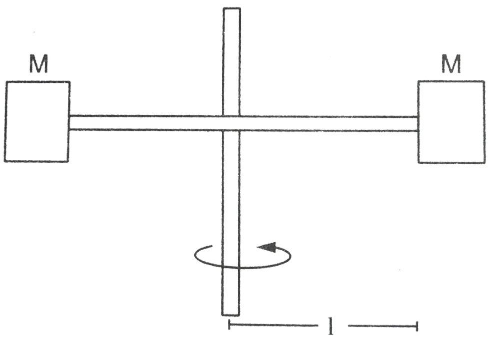


Figure 7-W6

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**10.** In a rotor, a hollow vertical cylindrical structure rotates about its axis and a person rests against the inner wall. At a particular speed of the rotor, the floor below the person is removed and the person hangs resting against the wall without any floor. If the radius of the rotor is 2m and the coefficient of static friction between the wall and the person is 0.2, find the minimum speed at which the floor may be removed Take $g = 10\frac{m}{s^2}$.

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**11.** A hemispherical bowl of radius R si set rotating abouv its axis of symmetry whichis kept vertical. A small blcok kept in the bowl rotates with the bowl without slippingn on its surface. If the surfaces of the bowl is mooth, and the abgel made by the radius through the block with the vertical is $\theta$, find the angular speed at which the bowl is rotating.

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**12.** A metal rign of mass m and radius R is placed on a smooth horizontal table and is set rotating abut its own axis in such a way that each part of the ring moves with a speed v. Find the tension in the ring.

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**13.** A table with smooth horiztonal surface is truning at an angular speed $\omega$ abouyt its axis. A groove is made on the surface along a radius and a particle is gently placed inside the groove at a distance a from the centre. Find the speed of the speed of the particle as its distance from teh centre becomes L.

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## Objective 1

**1.** When a particle moves in a circle with a uniform speed

A. its velocity and acceleration re both constant

B. its velocilty is constant but the acceleration changes

C. its acceleration is constant but the velocity changes

D. its velocity and acceleration both change.

**Answer: D**

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**2.** Two cars having masses $m_1$ and $m_2$ move in circles of radii $r_1$ and $r_2$ respectively. If they complete the circle is equal time the ratio of their angular speeds is $\frac{\omega_1}{\omega_2}$ is

A. $\frac{m_1}{m_2}$

B. $\frac{r_1}{r_2}$

C. $m_1 \frac{r_1}{m_2} r_2$

D. 1

**Answer: D**

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**3.** A car moves at a constant speed on a road as shown in figure. The normal force by the road on the car is $N_A$ and $N_B$ when it is at the points A and B respectively

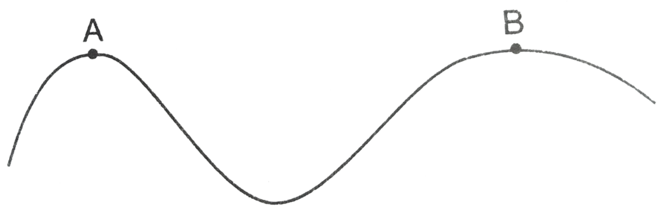

Figure 7-Q2

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A. $N_A = N_B$

B. $N_A > N_B$

C. $N_A < N_B$

D. insufficient informtion to decide the relation of $N_A$ and $N_B$

**Answer: C**

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**4.** A particle of mass m is observed from an inertial frame of reference and is found to move in a circle of radius r with a uniform speed v. The centrifugal force on it is

A. $\frac{mv^2}{r}$ towards the centre

B. $\frac{mv^2}{r}$ away from the centre

C. $\frac{mv^2}{r}$ along the tangent through the particle

D. zero

**Answer: D**

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**5.** A particle of mass m rotates with a uniform angular speed $\omega$. It is viewed from a frame rotating about the Z-axis with a uniform angular speed $\omega_0$. The centrifugal force on the particler is

A. $m\omega^2 a$

B. $m\omega^2 \_ 0a$

C. $m\left(\frac{\omega + \omega_0}{2}\right)^2 a$

D. $m\omega\omega_0 a$

**Answer: B**

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**6.** A particle is kept fixed on as turntable rotating uniformly. As seen from the ground the particle goes in a circle,its speed is 20 cm/s and acceleration is 20 cm/s^2 The particle is now shifted to a new positon to make the radius half of the original value. The new values of the speed and acceleration will be

A. $10c\frac{m}{s}, 10c\frac{m}{s^2}$

B. $10c\frac{m}{s}, 80c\frac{m}{s^2}$

C. $40c\frac{m}{s}, 10c\frac{m}{s^2}$

D. $40c\frac{m}{s}, 40c\frac{m}{s^2}$

**Answer: A**

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**7.** Water in a bucket is whirled in a vertical circle with a string attatched to it. The water does not fll down even when thebucket is inverted at the top of its path. We conclude that in this position

A. $mg = \frac{mv^2}{r}$

B. mg is greater than $\frac{mv^2}{r}$

C. mg is not greater than $\frac{mv^2}{r}$

D. `mg is not less than (mv^2)/r

**Answer: C**

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**8.** A stone of mass m tied to a string of length l is rotated in a circle with the other end of the string as the centre. The speed of the stone is v. If the string breaks, the stone will move

A. towards the centre

B. away from the centre

C. along a tangent

D. will stop.

**Answer: C**

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**9.** A coin placed on a rotating turntable just slips if it is placed at a distance of 4 cm from the centre. If the angular velocity of the turntable is doubled, it will just slip at a distance of

A. 1cm

B. 2cm

C. 4cm

D. 8cm

**Answer: A**

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**10.** A motorcycle is going on an overbridge of radius R. The driver maintains a constant speed. As the motorcycle is ascending on the overbridge, the normal force on it

A. increase

B. decrease

C. remains the same

D. fluctuates

**Answer: A**

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**11.** Three identical cars A,B and C are moving at the same speed on three bridges. The car A goes on a plane bridge, B on a bridge convex upward and C goes on a bridge concave upward. Let $F_A, F_B$ and $F_C$ be the normal forces exerted by the cars on the bridges when they are at the middle of bridges

A. $F_A$ is maximum of the three forces

B. $F_B$ is maximum of the three forces.

C. $F_C$ is maximum of the three forces.

D. $F_A = F_B = F_C$

**Answer: C**

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**12.** A car runs east to west and another car B of the same mass runs from west to east at the same path along the equator. A presses the track with a force $N_1$ and B presses the track with a force $N_2$. Then

A. $N_1 > N_2$

B. $N_1 < N_2$

C. $N_1 = N_2$

D. the information is insufficient to find the relation between $N_1$ and $N_2$.

**Answer: A**

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**13.** If the earth stops rotating, the apparent value of g on its surface will

A. increse everywhere

B. decrease everywhere

C. remain the same everywhere

D. increase at some places and remain the same at some other places.

**Answer: D**

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**14.** A rod of length L is pivoted at one end and is rotated with as uniform angular velocity in a horizontal plane. Let $T_1$ and $T_2$ be the tensions at the points L/4 and 3L/4 away from the pivoted ends.

A. $T_1 > T_2$

B. $T_2 > T_1$

C. $T_1 = T_2$

D. $The relation between$T_1 and T_2` depends on whether the rod rotates clockwise or anticlockwise.

**Answer: A**

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**15.** A simple pendulum having bob of mass m is suspended from the ceiling of a car used in a stunt film shooting. The car moves up along an inclined cliff at a speed v and makes a jump to leave the cliff and lands at some the top of the cliff. The tension in the string when the car is in air is

A. $mg$

B. $mg - \frac{mv^2}{R}$

C. $mg + \frac{mv^2}{R}$

D. zero

**Answer: D**

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**16.** Let $\theta$ denote the angular displacement of a simple pendulum oscillating in a vertical plane. If the mass of the bob is m, the tension in the string is $mg\cos\theta$

A. always

B. never

C. at the extreme position

D. at the mean position

**Answer: C**

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## Objective 2

**1.** An object follows a curved path. The following quantities may remain constant during the motion

A. speed

B. velocity

C. acceleration

D. magnitude of acceleration

**Answer: A::D**

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**2.** The position vector of a particle in a circular motion about the origin sweeps out equal areal in equal time. Its

A. velocity remains constant

B. speed remains constant

C. accelertion remains constant

D. tangential accelertion remains constant

**Answer: B::D**

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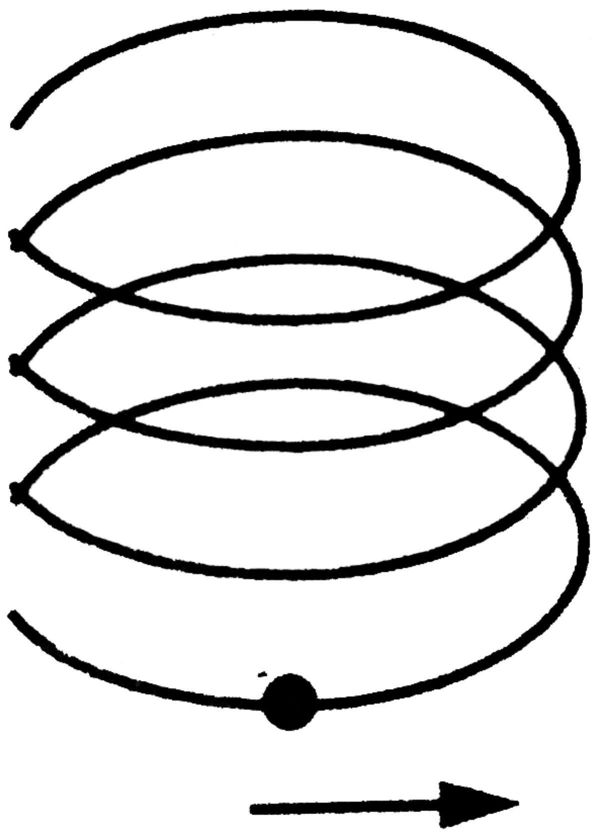
**3.** A particle is going in a spiral path as shown in figure with constant speed.



A. The velocity of the particle is constant.

B. The acceleration of the particle is constant

C. The magnitude of acceleration is constant.

D. The magnitude of accelertioin is decreasing continously

**Answer: C**

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**4.** A car of maas M is moving on a horizontal circular path of radius r. At an instant its speed is v and is increasing at a rate a.

A. The acceleration of the car is towards the centre of the path

B. The magnitude the frictional force on the car is greater than $\frac{mv^2}{r}$.

C. The friction coefficient between the ground and the car is not less than $\frac{a}{g}$.

D. The friction coefficient between the ground and the car is $\mu = \frac{\tan^{-1} v^2}{r} g$

**Answer: B::C**

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**5.** A circular road of radius r is banked for a speed v=40 km/hr. A car of mass m attempts to go on the circular road. The firctioncoefficient between the tyre and the road is negligible.

A. the car cannot make a turn without skidding.

B. If the car turns at a speed less than 40 km/hr, it will slip down

C. If the car turns at the correct speed of 40 km/hr, the force by the road on the car is equal to $\frac{mv^2}{r}$

D. If the car turns at the correct speed of 40 km/hr, the force by the road on the car is greater than mg as well as greater than `(mv^2)/r

**Answer: B::D**

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**6.** A person applies a constant force $\overrightarrow{F}$ on a particle of mass m and finds tht the particle movs in a circle of radius r with a uniform speed v as seen from an inertial frame of reference.

A. This is not possible

B. There are other forces on the particle

C. The resultant of the other forces is $\frac{mv^2}{r}$ towards the centre

D. The resultant of the other forces varies in magnitude as well as in direction.

**Answer: B::D**

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## Exercises

**1.** Find the accelerationof the moon with respect to the eath from the following data, Distance between the earth and the moon $= 3.85 \times 10^5$ km and the time taken by the moon to complete one revolution around the earth `=27.3days

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**2.** Find the acceleration of a particle placed on the surface of the earth at the equator due to earth's rotation. The diameter of earth =12800 km and it takes 24 hour for the earth to complete one revolution about its axis.

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**3.** A particle moves in circle of radius 1.0 cm at a speed given by v=2.0 t where v is in cm/s and t in seconeds. A. find the radia accelerationof the particle at t=1 s. b. Findthe tangential acceleration at t=1s. c.Find the magnitude of the aceleration at t=1s.

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**4.** A scooter weighing 150 g together with its rider moving at 36 km/hr is to take a turn of radius 30 m. What horizontal force on the scooter is needed to make the turn possible?

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**5.** A scooter weighing 150 kg together with its rider moving at 36 km/hr is to take a turn of radius 30 m. What horizontal force on the scooter is needed to make the turn possible?If the horizontal force needed for the turn in the previous problem is to be supplied by the normal force by the road what should be the proper angle of banking?

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**6.** A park has a radis of 10 m. If a vehicle goes round it at an averge speed of 18 km/hr, what shoud be the proper angle of banking?

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**7.** If the road of the previous problem is horizontal (no banking), what should be the minimum friction coefficeint so that a scooter going at 18 km/hr does not skid?

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**8.** A circular road of radius 50 m has the angel of banking equal to $30^0$. At what speed should a vehicle go on this road so that the friction is not used?

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**9.** In the Bohr model of hydrogen atom, the electron is treated as a particle going in a circle with the centre at the proton. The proton itself is assumed to be fixed in an inertial frame. The centripetal force is provided by the Coloumb attraction. In the ground state, the electron goes round the proton in a circle of radius $5.3 \times 10^{-11} m$. Find the speed of the electron in the ground state. Mass of the electron $= 9.1 \times 10^{-31} kg$ and charge of the electron $= 1.6 \times 10^{-19} C$.

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**10.** A stone is fastened to one end of a string and is whirled in a verticla circle of radius R.

Find the minimum speed the stone can have at the highest point of the circle.

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**11.** A ceiling fan has a diameter (of the circle through the outer edges of the three blades) of 120 cm and rpm 1500 at full speed.Consider a particle of mass 1 g sticking at the outer end of a blade. How much force does it experience when the fan runs at full speed? who exerts this force on the particle? How much force does the particle exert on the blade along its surface?

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**12.** As mosquito is sitting on an L.P. record disc rotating on a trun tabel at $33\frac{1}{3}$ revolutions per minute. The distance of the mosquito from the centre of the turn table is 10 cm. Show that the friction coefficient between the record and the mosquito is greater than $\frac{\pi^2}{81}$. Take $g = 10\frac{m}{s^2}$

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**13.** A simple pendulum is suspended from the ceiling of a car taking a turn of radius 10 m at a speed of 36 km/h. Find the angle made by the string of the pendulum with the vertical if this angle does not change during the turn. Take $g = 10\frac{m}{s^2}$.

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**14.** The bob of a simple pendulum of length 1 m has mass 100 g and a speed of 1.4 m/s at the lowest point in its path. Find the tension in the stirng at this instant.

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**15.** Suppose the bob of the previous problem has a speed of 1.4 m/s when the string makes an angle of 0.20 radian with the vertical. Find the tension at this instant. You can use

$\cos\theta = 1 - \frac{\theta^2}{2}$ and $\sin\theta = \theta$ for small theta`.

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16. Suppose the amplitude of a simple pendulum having a bob of mass m is $\theta_0$. Find the tension in the string when the bob is at its extreme position.

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**17.** A person stands on a spring balance at the equator. a.By what fraction is the balance reading less than his true weight? b.If the speed of earth's rotation is increased by such an amount that the balance reading is half the true weight, what will be the lenght of the day in this case?

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**18.** A turn of radius 20 m is banked for the vehicles going at a speed of 36km/h. If the coefficient of static friction between the road and the tyre is 0.4, what are the possible speeds of a vehicle so that it neither slips down nor skids up?

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**19.** A motorcycle has to move with a consatnt speed on an overbridge which is in the form of as circular arc of radius R and has a total length L. Suppose the motorcycle starts from the highest point. a. what can its maximum velocity be for which the contact with the road is not broken at the highest point? b. If the motorcycle goes at speed $\frac{1}{\sqrt{2}}$ times the maximum found in part a. where will it lose the contact with the road? c. What maximum uniform speed can it maintain on the bridge if it does not lose contact anywhere on the bridge?

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**20.** A car starts rest, on a horizontal circular road of radius R, the tangential acceleration of the car is a. The friction coefficient between the road and the tyre is $\mu$ Find the speed at which car will skid and also find the distance after travelling it skids.

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**21.** A block of mass $m$ is kept on a horizontal ruler . The friction coefficient between the ruler and the block is $\mu$ . The ruler is fixed at one end the block is at a distance L from the fixed end . The ruler is rotated about the fixed end in the horizontal plane through the fixed end

a. What can the maximum angular speed be for which the block does not slip?

b. If the angular speed of the ruler is uniform increase from zero at an angular acceleration a at angular speed will the block slip?

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**22.** A track consists of two circular pars ABC and CDE of equal radius 100 m and joined smoothly as shown in figure.Each part subtends a right angle at its centre. A cycle weighing 100 kg together with rider travels at a constant speed of 18 km/h on the track. A. Find the normal contact force by the road on the cycle when it is at B and at D. b.Find the force of friction exerted by the track on the tyres when the cycle is at B,C and D. c. Find the normal force between the road and the cycle just before and just after the cycle crosses C. d. What should be the minimum friction coefficient between the road and the tyre, which will ensure that the cyclist can move with constant speed? Take $g = 10\frac{m}{s^2}$

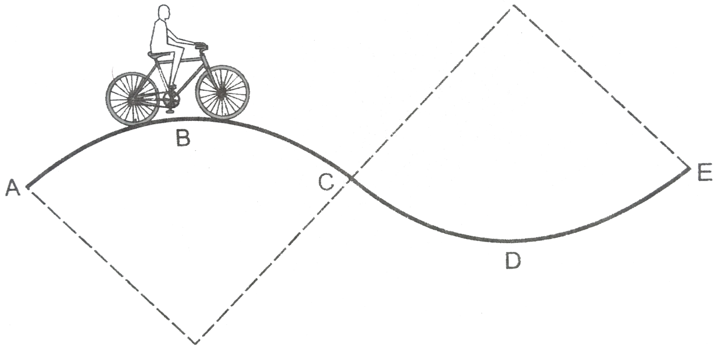


Figure 7-E1

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**23.** In a children's park a heavy rod is pivoted at the centre and is made to rotate about the pivot so that the rod always remains horizontal. Two kids hold the rod near the ends and thus rotate with the rod figure. Let the mas of each kid be 15 kg, the distance between the points of the rod where the two kids hold it be 3.0 m and suppose that the rod rotates at the rate of 20 revolutions per minute. Find the force of friction exerted by the rod on one of the kids.

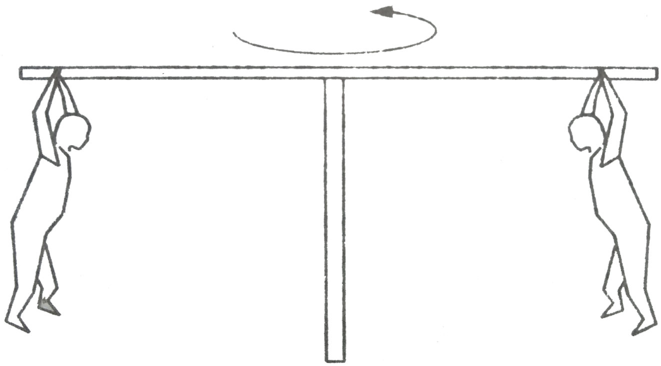

Figure 7-E2

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**24.** A hemispherical bowl of radius R is rotated about its axis of symmetry which is kept vertical.A small block is kept in the bowl at a position where the radius makes an angle $\theta$

with the vertical. The block rotates with the bowl without any slipping. The friction coefficient between the block and the bowl surface is $\mu$. Find the range of the angular speed for which the block will not slip.

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**25.** A particle is projected with a speed u at angle $\theta$ with the horizontal. Consider a small part of its path ner the highest position and take it approximately to be a circular arc. What is the rdius of this circle? This radius is called the adius of curvature of the curve at the point.

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**26.** What is the radius of curvature of the parabola traced out by the projectile in which a particle is projected with a speed u at an angle $\theta$ with the horizontal, at a point where the velocity of particle makes an angle $\theta/2$ with the horizontal.

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**27.** A block is mass m moves on as horizontal circle against the wall of a cylindrical room of radius R. The floor of the room on which the block moves is smooth but the friction coefficient between the wall and the block is $\mu$. The block is given an initial speed $v_0$. As a function of the speed v write a. the normal force by the wall on the block. b. the frictional force by the wall and c. the tangential acceleration of the block. d. Integrate the tangential acceleration $\left(\frac{dv}{dt}=v\frac{dv}{ds}\right)$ to obtain the speed of the block after one revoluton.

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**28.** A table with smooth horizontal surface is fixed in a cabin that rotates with a uniform angular velocity $\omega$ in a circular pathof radius R. A smooth groove AB of length $L(< < R)$ is made on the surface of the table. The groove makes an angle$\theta$ with the radius OA of the circle in which the cabin rotates. A small particle is kept at the point A in the groove and is released to move along AB. Find the time taken by tehparticle to reach the point B.

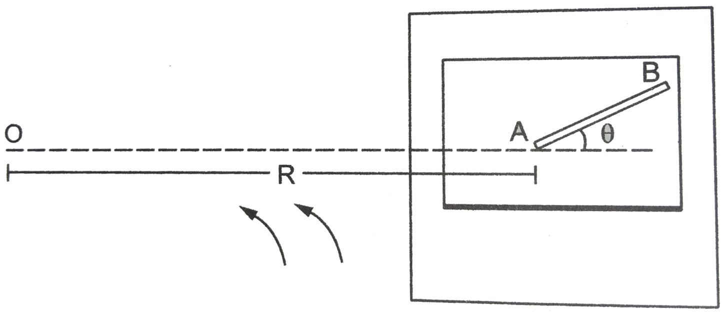


Figure 7-E3

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**29.** A car moving at a speed of 36 km/hr is taking a turn on a circular road of radius 50 m.

A small wooden plate is kept on the seat with its plane perpendicular to the radius of the circular road figure. A small bock of mass 100 g is kept on the seat which rests against the plate. The friction coefficient between the block and the plate is $\mu = 0.58.$ a. Find the normal contact force exerted by the plate on the block. b. The plate is slowly turned so that the angle between the normal to the plate and the radius of the road slowly increases Find the angle at which the block will just start sliding on the plate.

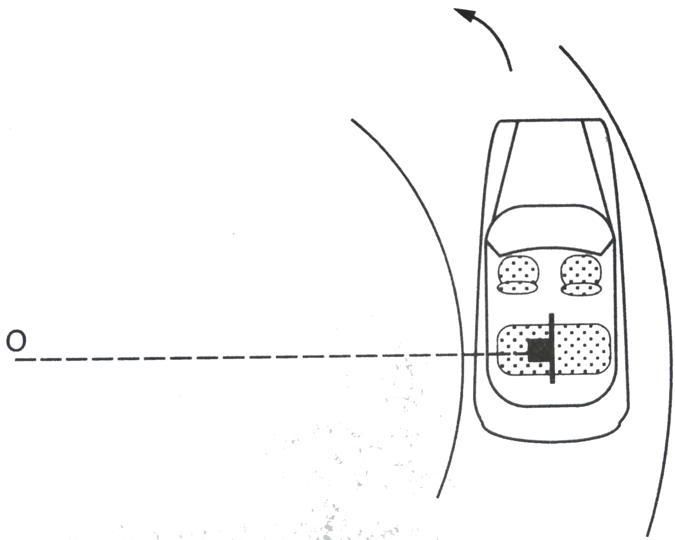


Figure 7-E4

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**30.** A table with smooth horizontal surface is placed in a cabin which moves in a circle of a large radius R Figure. A smooth pulley of small radius is fastened to the table. Two masses m and 2m placed on te tableare connected through a string going over the pulley. Initially the masses are held by a personwith the strings aslong teh outward radius and then the system is released from rest (with respect to the cabin). Find the magnitude of the initial acceleration of the mases as seen from the cabin and the tension in the starting.

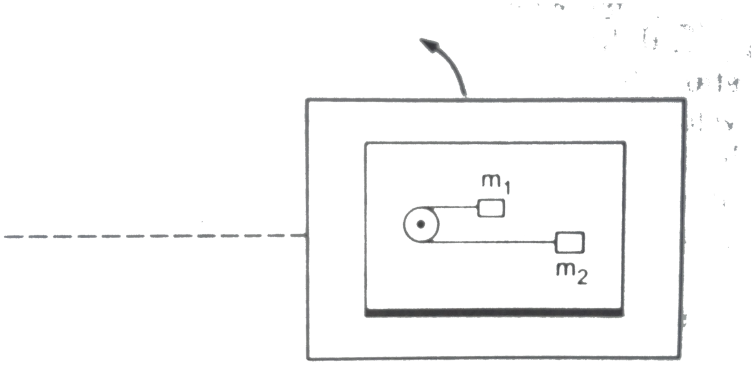


Figure 7-E5

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## Question For Short Answer

**1.** You are driving a motorcycle ona horizontal raod. It is moving with a uniform velocity. Is it possibel to accelerate the motorcycle wilthout putting higher petrol input rate into the engine?

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**2.** Some washing machines have cloth driers. It contains a drum in which wet clothes are kept. As the drum rotates, the water particles get separated from the cloth. The general description of this action is that the "Centrifugal force throws the water particles away from the drum". Comment on this statement from the viewpoint of an observer rotating with the drum and the observer who is washing the clothes.

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**3.** A small coin is placed on a record roting at $33\frac{1}{3}$ rev/minute. The coin does not slip on the record. Where does it get the required centripetal fore from?

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**4.** A bird while flying takes a left turn,from where does it get the centripetal force ?

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**5.** Is it necssary to express all angles in radianwhile using the equation $\omega = \omega_0 + \alpha t$?

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**6.** After a good meal at a party you wash your hands and find that you have forgotten to bring your handkerchief. You shake your hands vigorusly to remove the water as much as you can. Why is water removed in this process?

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**7.** A smooth block loosely fits in a circular tube placed on a horizontal surface. The block moves in as uniform circular motion along the tube figure. Which wall (inner or outer) will exert a nonzero normal contact force on the block?

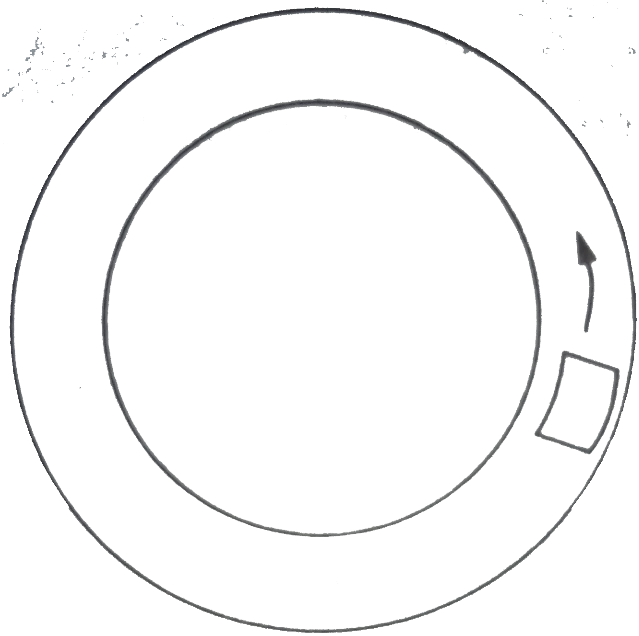

Figure 7-Q1

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**8.** Consider the circular motion f the earth around the sun. Which of the following statements is more appropriate? a. Gravitational attraction of the sun on the earth is equal to the centripetal force. b. Grvitational attraction of the sun on the earth is the centripetal force.

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**9.** A car driver going at speed $v$ suddenly finds a wide wall at a distance $r$ . Should he apply breakes or turn the car in a circle of radius $r$ to avoid hitting the wall.

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**10.** A heavy mass m is hanging from a string in equilibrium without breaking it. When this same mass is set into oscillation, the string breaks, Explain.

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