PHYSICS

BOOKS - BHARATI BHAWAN PHYSICS (HINGLISH)

CENTRIPITAL AND CENTRIFUGAL FORCES

Examples

1. A train is moving at the rate of 60 km per hour around a curve of radius 500 m and the distance between the rails is 170 cm. By how much the outer rail be raised above the inner one so that there may be no lateral thrust on the outer rails ? $\left(g = 9.8ms^{-2}\right)$

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2. The roadway bridge over a cannot is in the form of an arc of a circle of radius 20 m. what

is the maximum speed with which a car cann cross the bridge without leaving the ground at the highet point ?

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3. A small body of mass 1/2 kg is tied to one end of a string of length 1m. With what horizontal velocity must the body be projected so that it may go round the peg to which the other end of the string is attached without slackening of the string at the highest point ?

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4. Show that the maximum tension in the string of a simple pendulum, when the amplitude θ_0 is small, is $mg\left(1+\theta_0^2\right)$. At what position of the pendulum is the tension maximum ?

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5. The CG of a loaded taxi is 1.5 m above the ground and the distance between its wheels is

2 m. What is the maximum speed with which it can go round an unbanked curved of radisu 100 m without being turned upside down ? What minimum value of the coefficient of friction would be needed at this speed ?

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6. With what velocity should a satellite be launched in the horizontalm direction at a height 300 km so that it can revolve round the

earth ? (g at a height 300 km = $7.5ms^{-2}$ and radius of earth = 6400 km)

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7. A particle of mass m moves in a circle of radius R in such a way that its speed (v) varies with distance (s) as $v = a\sqrt{s}$ where a is a constant. Calcualte the acceleration and force on the particle.

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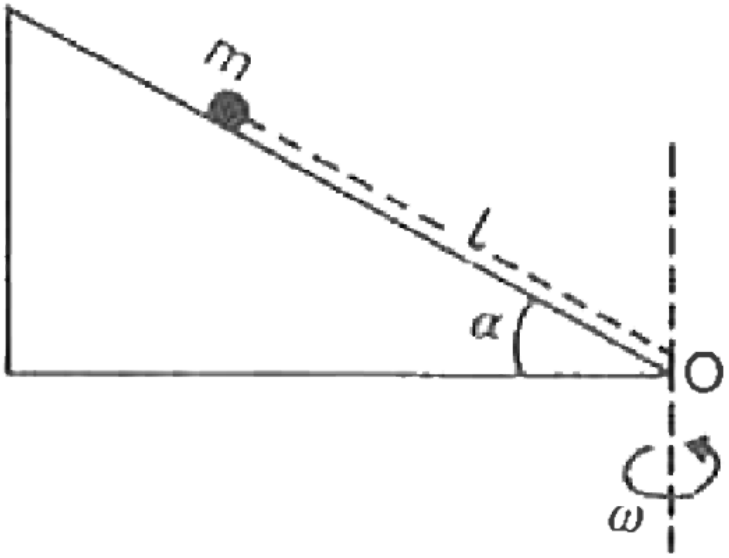
8. A ball is placed on a smooth chute inclined at an angle $\alpha = 30^\circ$ to the horizontal and rotating at frequency n=30 rpm about a vertical axis passing through its lower end. At what distance from the end of the chute does the ball rest ?



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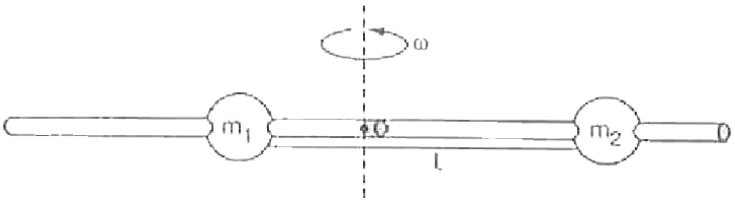
9. Two balls of masses $m_1 = 0.5kg$ and $m_2 = 0.3kg$ are connected by a nonstretchable string and slipped on to a horizontal , light rod. The rod is rotated with $\omega = 110$ rpm about a vertical axis passing through its centre. Find the tension of the string and the distance of the masses from the axis of rotation if $l = 20$ cm is the length of the string. Is the equilibrium of the balls

stable ?



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10. A cyclist rides along a circular path in a horizontal plane where the coefficient of friction varies with distance from the centre O of the circular path as $\mu = \mu_0\left(1 - \frac{r}{R}\right)$ where R is the maximum distance up to which the road is rough

Find the radius of the circular path along which the cyclist can ride with maximum velocity. What is this maximum velocity ?

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11. A particle of mass $m = 2$ kg is suspended in a vertical plane by two strings - one horizontal and the other inclined to the vertical by $\alpha = 30^\circ$. Find the tension of the inclined string (a) an instant before the

horizontal one is cut, (b) an instant after the horizontal one is cut.

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12. A particle moves with deceleration along a circle of radius R so that at any moment its tangential and normal accelerations are equal in moduli. At the initial moment $t = 0$ the velocity of the point equals v_0. Find (a) the velocity of the point as a function of t and s ,

(b) the resultant acceleration modulus as a function of v.

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Exercises A

1. A bucket containing water is tied to one end of a rope 2 m long and rotated in a circle about the other end in a vertical plane. Find the minimum number of rotations per minute

in order that water may not spill. $(g = 9.8ms^{-2})$.

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2. A motor-cyclist goes round a circular race course ar 150 kmph. How far from the vertical must be lean inward to keep his balance if the track is 1.5 km long ?

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3. In a circus a motorcyclist shows a trick of moving in a vertical plane without falling. Explain the physics of this track. What is the minimum speed of the motorcylist if the radius of the iron cage in which he shows his trick is 8 m ?

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4. A gramophone disc is set revolving in a horizontal plane at the rate of $33\frac{1}{2}$

revolutions per minute. It is found that a small coin placed on the disc will remain there if its centre is not more than 5 cm from the axis of rotation. Calculate the coefficient of friction between the coin and the disc

[Hint : Centripetal force $= m\omega^2 r =$ Frictional force $= \mu N = \mu mg$]

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5. The CG of a loaded truck is at a height of 3 m above the ground and the distance between

its wheels is 3m. What is the maximum speed with which it can go round a curved road of radius 200 m without turning turtle ?

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6. What is the maximum speed with which an automobile can round an unbanked curve of radius 200 m without skidding if the coefficient of friction between tyre and road is 0.3 ? $\left(g = 9.8ms^{-2}\right)$

[Hint : Centripetal force $= \frac{mv^2}{r} = \mu N = \mu mg$]

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7. Calculate the apparent weight if a body of 10 kg of place of latitude 60°. The radius of the earth $= 6.4 \times 10^6$ m

[Hint : Apparent weight $= mg - mv^2 \frac{\cos^2 \lambda}{r}$ where λ is the latitude of the place

$= mg - m\omega^2 r \cos^2 \lambda N$

$= \left(m - m\omega^2 r \cos^2 \lambda / g\right) kg$]

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8. A small body is tied to an end of an inextensible string of negligible mass and length r, the other end being clamped to a rigid support. What is the minimum velocity with which the body must be projected horizontally so that it can go completely round a vertical circle without slakening of the string at the highest point ?

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9. An artificial satellite is revolving in a circular orbit at a height of 600 km from the earth's surface. If its time of revolution be 100 minutes, calculate the acceleration due to gravity acting on it towards the earth. Radius of earth $= 6.4 \times 10^6$ m

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10. A mass m on a frictionless table is attached to a hanging mass M by a cord length l

passing through a hole in the table. Find the speed with which m must spin for M to stay at the highest point. If this speedis doubled, what will be the force with which M will press the table ?

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11. A road is banked correctly for a speed of 40 kmph. What is the maximum speed with which a car can negotiate the bend without skidding if the coefficient of friction between road and

tyre is 0.3 and radius of the bend is 1 km ?

[Hint : $v_m^2 = v^2 + \mu gr$]

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12. The artificial satellite Aryabhatta was reported to revolve round the earth in 96.2 minutes at an average height of 600 km. With what velocity was it projected ? What was the acceleration due to gravity on the satellite ?

(Radius of the earth = 6400 km)

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13. The bob of a simple pendulum of length 1m hangs at rest. It is suddenly projected horizontally with velocity $10ms^{-1}$. Calculate the velocity of the bob and tension of the string when it is horizontal. The mass of the bob is $\frac{1}{2}$kg.

[Hint : See worked out example 4]

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14. A small brass bob is revolving in a horizontal circle with a constant speed of $2ms^{-1}$ at the end of a string of length 1 m. Find the time required for one revolution of the body. What angle does the string make with the vertical ?

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15. A roadway bridge over a rivulet is in the form of quarter of a circle of radius 60 m.

What is the maximum speed with which a car can pass over the bridge without leaving the ground at any point ?

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16. A string of length 1m is fixed at one end and carries a mass of 1 kg at the other end. The string makes $2/\pi$ revolutions per second around a vertical axis passing through the fixed end. Calculate (i) angle of inclination of the string with the vertical, (ii) the tension in

the strong and (iii) the linear velocity of the mass.

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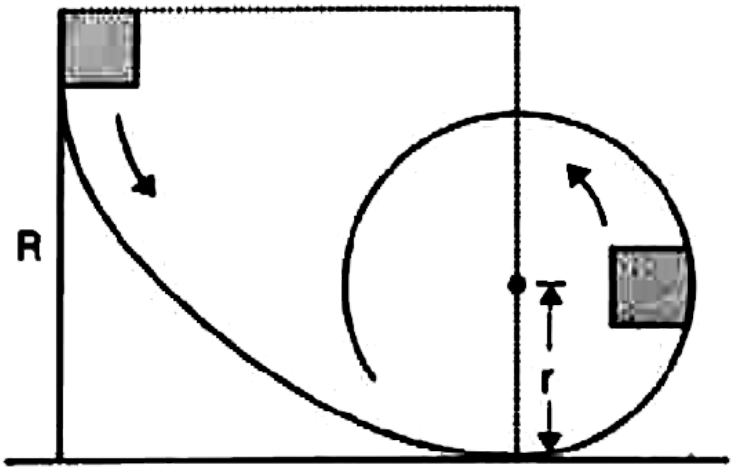
17. A small block of mass m slides along a frictionless loop-the-loop (loop inside loop) track. What should be the ratio of the radius of the outer loop to the radius of the inner loop so that the the block may not lose contact at the highest point of the inner loop

?



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18. Calculate the height of the Apple (India's first geostationary satellite) above the surface of the earth (Radius of the earth = 6400 km and $g = 9.8ms^{-2}$)

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Exercises B

1. A stone weighing 1 kg is ties to a string of 1m length and whirled over the horizontal top of a rough plane with a speed of $2ms^{-1}$. Calculate the tension of the string if the coefficient of friction between the table and the stone is 0.3

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2. Calculate the frequency of revolution of an electron in a hydrogen atom assuming that the radius of the first Bohr orbit is 5×10^{-11} m. Mass of electron $= 9.0 \times 10^{-31} kg$, charge of electron $= 1.6 \times 10^{-19} C$, $\frac{1}{4\pi\varepsilon_0} = 9 \times 10^9 SI$ units.

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3. A brass bob is suspended by an inextensible weightless string of length l from a peg fixed

on a vertical wall. A nail is fixed in the wall at a distance d vertically below the point of suspension of the string. The bob is then drawn to a position where the string becomes horizontal and it is released from there. Show that d must be at least $0.6l$ if the bob is to swing completely around in a circle centred on the nail.

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4. A point mass m starts to slide from rest from the top of a smooth solid sphere of radius r. Calculate the angle at which the mass flies off the sphere. If there is friction between the mass and sphere, does the mass fly off at a greater or lesser angle ?

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5. A very small cube of mass m is placed on the inside of a conial funnelof semivertical angle

$(\pi/2 - \theta)$. The funnel is then set in rotation. If the coefficient of static friction between the cube and the funnel is μ and the centre of the cube is at a distance r from the axis of rotation, what are the largest and smallest angular velocities with which the funnel can be rotated so that the block will not move with respect to the funnel ?

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6. A simple pendulum of length l is suspended in a car that is travelling with a constant speed v around a circle of radius r. If the pendulum undergoes small oscillations about its equilibrium position , what will its freqeuency of oscillation be ?

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7. A body is suspended on a spring balance in a ship sailing along the equator with a speed v

. Show that the scale reading will be very close to $W_0\left(1 \pm \frac{2\omega v}{g}\right)$, where ω is the angular speed of the earth and W_0 is the reading of spring balance when the ship is at rest. Explain the plus or minus sign

[Hint : $W_0 = mg - m\omega^2 R, W = mg - m\frac{(m\omega + v)^2}{R}$ when the ship is moving from west to east]

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8. A satellite revolving in a circular equatorial orbit of radius $R = 2 \times 10^4$ km from west to east appears over a certain point at the equator every $t = 11.6$ hours. Calculate the mass of the earth. The gravitational contant $G = 6.67 \times 10^{-11} SI$ units.

[Hint : $\omega_{app} = \omega_{\text{earth}}$ or $\omega_{\text{real}} = 2\pi\left(\frac{1}{T} + \frac{1}{t}\right)$

]

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9. A 40-kg mass hanging at the end of a rope of length l. Oscillates in a vertical plane with an angular of θ_0. What is the tension in the rope when it makes an angle θ with the vertial ? If the breaking strength of the rope is 80 kg, what is the maximum angular amplitude with which the mass can oscillate without the rope breaking ?

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10. A large mass M and a small mass m hang at the two ends of string passing through a smooth tube. The mass m moves around in a circular path in a horizontal plane. The length of the string from the mass m to the top of the tube of the tube is l and θ is the angle this length makes with the vertical. What should be the frequency of rotation of the mass m so that M remains stationary ?

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11. In problem 17 if the mass m is allowed to fall from a height $2R$, find the reaction of the track on the sliding mass the lowest point, at the highest point, at the mid-point. Take $R:r = 5:2$

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12. In the figure of problem 17 if the block starts from rest when $R = 5r$, what is the reaction of the inner track on the sliding mass at the highest point ? From what height

should it fall so that it may exert a force equal to its weight on the track at the highesth point ?

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13. Due to rotation of the earth, a plumb bob may not hang along the earth's gravitational pull, but may deviate slightly from this direction. Calculate the deviation (a) at 45° latitude, (b) at the poles (c) at the equator.

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14. A mass m is moving inside a vertical circular track of radius R. There is no friction. Find the minimum speed $(v_{\min})$ at which m will round the circle without losing contact with the track. Suppose $v = 0.775v_{\min}$. The mass will move up to certain point P where it will lose contact with the track. Find the angular heightr of the track.

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15. If a simple pendulum of mass m is released from a horizontal position, find the tension in the string as a function of the angle θ with the horizontal.

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16. A simple pendulum consists of a heavy mass supported by a light, thin rod. It is held inverted in the position of unstable equilibrium and then released. Find the angle

defining the position of its downward fall at which the axial force in the rod changes from compression to tension.

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17. In problem 15 if a motor-cyclist passes over the bridge at $18ms^{-1}$, atb which point will the reaction become equal to zero ?

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18. Calculate the ratio of the reaction of a convex bridge at the highest point to the reaction of a concave bridge at its lowest point when a car passes at 30 kmph and the radius of either bridge is 20 m.

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19. A heavy particle of mass 2kg is tied to two strings, each of length 25 cm and they are tied to two points 30 cm apart on the same vertical

line. The particle is whirled in a horizontal plane with a speed of $1.8ms^{-1}$. Calculate the ratio of the tensions of the two strings.

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20. A body is suspended by a string of length 1 m and is projected horizontally with a velocity of $4ms^{-1}$ Calculate its tangential and radial accelerations when the string rises by 60° from its initial position.

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21. A mass of 0.675 kg on a frictionless table is attached to a string which passes through a hole in the table at the centre. If the radius of the circle in which the mass rotates, is 5 m when its speed is $10ms^{-1}$, find the tension of the string. It is found that on drawing down the string by 0.2 m, the tension is increased 4.63 times. Calculate the work done by the string on the revolving mass during the reduction of the radius.

[Hint : Apply work-energy theorem to find work done by the force]

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22. A particle is placed inside a hemispherical bowl which rotates about its vertical axis with constant angular speed ω. It is just prevented from sliding down when the line joining it to the centre of the hemisphere is 45° with the vertical. The radius of the bowl is $10\sqrt{2}$m. The coefficient of friction between the particle and

the bowl is 0.5 and $g = 10ms^{-2}$. Find the magnitude of ω.

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23. A rigid rod of length l but of negligible mass has heavy mass m attached to one end and is hinged freely at the upper end. It is inverted and then released. What is its speed at the lowest point and what is the tension in the suspension at that instant ? When the same is released from the horizontal position,

at what angle from the vertical will the tension in the suspension equal the weight ?

[Hint : Consider conservation of energy and dynamics of circular motion]

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24. Suppose that the string of a simple pendulum is elastic and k is its force constant. Show that the string will stretch by an amount $\Delta l = \frac{3mg}{k}$ when $\Delta l << l$. Also show that the speed of the bob at the bottom is

$v = \sqrt{2g\left(l - \frac{3mg}{2k}\right)}$. The amplitude of the pendulum is 90°.

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25. A rod of length l rotates with uniform velocity ω about an axis perpendicular to its length and passing through its end. Calculate the force exerted by one-half on this other.

[Hint : Consider the dynamics of circular motion of an element at a distance x and

thickness dx. Assume that T is the tension at a distance x]

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26. A small body is placed on the top of a smooth sphere of radius R. Then the sphere is imparted a constant acceleration w_0 in the horizontal direction and the body begins sliding down. Find:

(a) the velocity of the body relative to the sphere at the moment of break-off,

(b) the angle θ_0 between the vertical and the radius vector drawn from the centre of the sphere to the break-off point, calculate θ_0 for $w_0 = g$.

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27. A particle mass m begins to slide down a fixed smooth sphere from the top of its vertical diameter. Calculate its tangential acceleration, radial acceleration and total acceleration when it breaks off.

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28. A particle of mass m is suspended by a string of length l from a fixed rigid support. Particle is imparted a horizontal velocity $u = \sqrt{2gl}$. Find the angle made by the string with the vertical when the acceleration of the particle is inclined to the string by 45°?

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29. A man stands on a running train (speed 60 kmph) with his feet 60 m apart facing forward. If the train rounds a curve of radius 450 m in a counterclockwise sense, what per cent of his weight rests on his left leg, if his centre of mass is 1.2 m above the floor ?

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30. A stone is thrown horizontally with a velocity of $10m/\sec.$ Find the radius of

curvature of it's trajectory at the end of $3s$ after motion began. $\left(g = 10m/s^2\right)$

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31. A body is weighed on a spring balance in the wagon of a train travelling round a bend in the track which is banked in the usual way. The balance shows increase in weight by fraction n. The balance can revolve about its support point and remains at right angles to

the floor of the wagon when rounding the bend when the train is travelling at speed v ?

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32. Two particles A and B move anticlockwise with the same speed v in a circle of radius R and are diametrically opposite to each other. At $t = 0$, A is given a constant accelerartion (tangential) $a_t = \frac{72v^2}{25\pi R}$. Calculate the time in which a collides with B, the angle traced by A,

its angular velocity and radial acceleration at the time of collision.

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33. A conical pendulum consisting of rigid rod of length l and mass m rotates uniformly about vertical axis with angular velocity ω. Find the angle θ between the rod and the vertical

[Hint : Equate the moments of centrifugal

forces on elementary masses to the moment of gravity]

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34. A ring of mass m and radius R is being rotated about its axis with constant angular velocity ω in the gravity free space. Find tension in the ring.

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35. Water flows along a horizontal pipe with a curve having a radius of $R = 20$ m. Find the lateral pressure of the water caused by the centrifugal force. The pipe diameter d = 20 cm, and m = 300 tons of water pass through the pipe in t = 2 hours.

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36. A rough horizontal plate rotates with a constant angular velocity w about its vertical

axis. A particle of mass m lies on the plate at a distance $\frac{5a}{4}$ from the axes. If the coefficient of friction is $\frac{1}{3}$ and the particle remains at rest relative to the plane, show that $w \leq \sqrt{\frac{4g}{15a}}$. The particle is now connected to axis by a horizontal elastic string, of natural length a and modulus 3 mg. If the particle remains at rest relative to the plate and at a distance $\frac{5a}{4}$, show that the greatest possible angular velocity is $\sqrt{\frac{13}{15}.\frac{g}{a}}$ and find the least possible velocity.

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