# PHYSICS

# BOOKS - RESNICK AND HALLIDAY PHYSICS (HINGLISH)

# RIGID BODY DYNAMICS-II

## Sample Problem

1. The current land-speed record was set in the Black Rock Desert of Nevada in 1997 by the jet-powered car Thrust SSC. The car's speed was

$1222 km/h$ in one direction and $1233 km/h$ in the opposite direction. Both speeds exceeded the speed of sound at that location (1207 km/h). Setting the land-speed record was obviously very dangerous for many reasons. One of them had to do with the car's wheels. Approximate each wheel on the car Thrust SSC as a disk of uniform thickness and mass M = 170 kg and assume smooth rolling. When the car's speed was 1233 km/h, what was the kinetic energy of each wheel?

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**2.** A uniform ball, of mass M = 6.00 kg and radius R, rolls smoothly from rest down a ramp at angle $\theta = 30.0^\circ$ .

(a) The ball descends a vertical height h = 1.20 m to reach the bottom of the ramp. What is its speed at the bottom?

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**3.** A uniform ball, of mass M = 6.00 kg and radius R, rolls smoothly from rest down a ramp at angle $\theta = 30.0^\circ$ .

What are the magnitude and direction of the frictional force on the ball as it rolls down the ramp?

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**4.** A yo-yo has mass M = 0.550 kg and rotational inertia $I = 3.40 \times 10^{-4} kgm^2$?. It rolls from rest down a string of length L = 17.0 cm. What is its angular speed at the bottom?

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**5.** A yo-yo has mass M 0.550 kg, axle radius $R_0 = 3.2mm$, and rotational inertia $l = 3.4 \times 10^{-4} kgm^2$ about its rotation axis. Assume that the string has negligible mass and thickness.

(a) What is the linear acceleration of the yo-yo as it rolls down the string from rest?

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**6.** A yo-yo has mass M 0.550 kg, axle radius $R_0 = 3.2mm$, and rotational inertia $l = 3.4 \times 10^{-4} kgm^2$ about its rotation axis.

Assume that the string has negligible mass and thickness.

What is the tension in the string as the yo-yo descends?

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**7.** A wheel rolls smoothly along a floor while being accelerating horizontally by a force $\overrightarrow{F}_n$ applied at its top. The wheel has radius R = 0.500 m, mass m = 1.60 kg, and acceleration magnitude $a = 2.00 m / s^2$. The frictional force on the wheel is in the forward direction and has magnitude f = 1.80 N. What is the rotational inertia of the wheel?

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**8.** A uniform hoop, disk, and sphere, with the same mass M and same radius R, are released simultaneously from rest at the top of a ramp of length L = 2.5 m and angle $\theta = 12^{\circ}$ with the horizontal. The objects roll smoothly down the ramp.

(a) Which object wins the race to the bottom of the ramp?

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**9.** A uniform hoop, disk, and sphere, with the same mass M and same radius R, are released simultaneously from rest at the top of a ramp of length L = 2.5 m and angle $\theta = 12^\circ$ with the horizontal. The objects roll smoothly down the ramp.

What is $v_{\text{com}}$ for each object at the bottom of the ramp?

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**10.** Kinetic energy distribution in a rolling object. Consider a hoop, a disk, and a sphere, each of mass

M and radius R, that roll smoothly along a horizontal table. For each, what fraction of its kinetic energy is associated with the translation of its center of mass?

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**11.** a uniform beam, of length L and mass m = 1.8 kg, is at rest on two scales. A uniform block, with mass M = 2.7 kg, is at rest on the beam, with its center a distance $L/4$ from the beam's left end. What do the scales read?

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**12.** Figure 11-16a shows a safe (mass M = 430 kg) hanging by a rope (negligible mass) from a boom (a = 1.9 m and b = 2.5 m) that consists of a uniform hinged beam (m=85 kg) and horizontal cable (negligible mass).

What is the tension $T_c$ in the cable? In other words, what is the magnitude of the force $\vec{T}_c$ on the beam from the cable?

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**13.** Figure 11-16a shows a safe (mass M = 430 kg) hanging by a rope (negligible mass) from a boom (a

= 1.9 m and b = 2.5 m) that consists of a uniform hinged beam (m=85 kg) and horizontal cable (negligible mass).

Find the magnitude F of the net force on the beam from the hinge.

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**14.** a ladder of length L=12 m and mass m = 45 kg leans against a slick wall (that is, there is no friction between the ladder and the wall). The ladder's upper end is at height h = 9.3 m above the pavement on which the lower end is supported (the pavement is not frictionless). The ladder's center of mass is $L/3$ from the lower end, along the length of the ladder. A firefighter of mass M = 72 kg climbs the ladder until her center of mass is $L/2$ from the lower end. What then are the magnitudes of the forces on the ladder from the wall and the pavement?

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**15.** Let's assume that the Tower of Pisa is a uniform hollow cylinder of radius R = 9.8 m and height h=60 m. The center of Mass is located at height $h/2$, along the cylinder's central axis. In Fig. 11-18a, the cylinder is upright. In Fig. 11-18b, it leans rightward (loward the tower's southern wall) by $\theta = 5.5$, which shifts the com by a distance d. Let's assume that the ground exerts only two forces on the tower. A normal force $\overrightarrow{F}_{NL} = 0$ acts on the left (northern) wall, and a normal force we acts on the right (southern) wall. By what percent does the magnitude Far increase because of the leaning?

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**16.** The crate in Fig. 11-20 has dimensions l by h and the ramp is inclined at $\theta$ to the horizontal. Find the maximum $\theta$ for which it does not topple. Coefficient of friction between ramp and crate is $\mu$.

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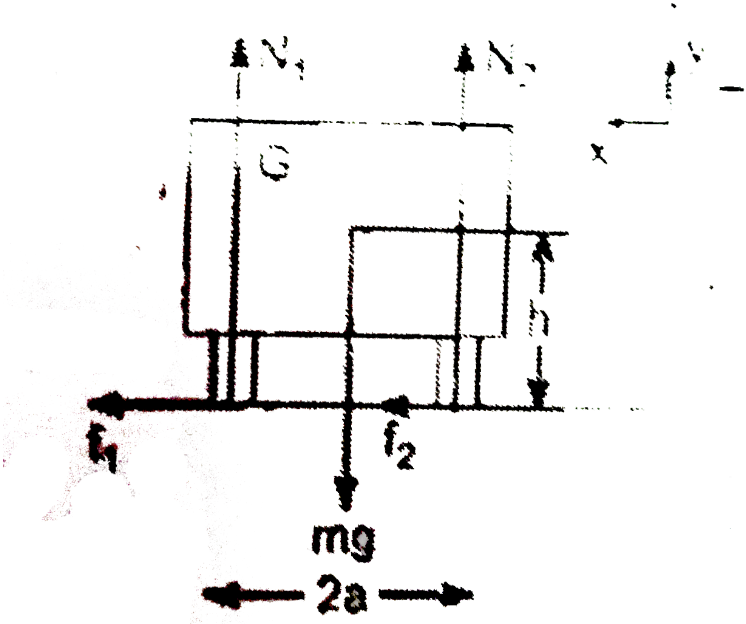
**17.** A car of mass $m$ travelling at speed $v$ moves on a horizontal track. The centre of mass of the car describes a circle of radius $r$. If $2a$ is the separation of the inner and outer wheels and $h$ is the height of the centre of mass above the ground, show that the limiting speed beyond which the car will overturn in given by

$$v^2 = \frac{gra}{h}$$

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**18.** A cylinder of radius r is rolling purely on ground, find out if the number of particles having velocity greater than v are more than those having velocity less than $v_c$

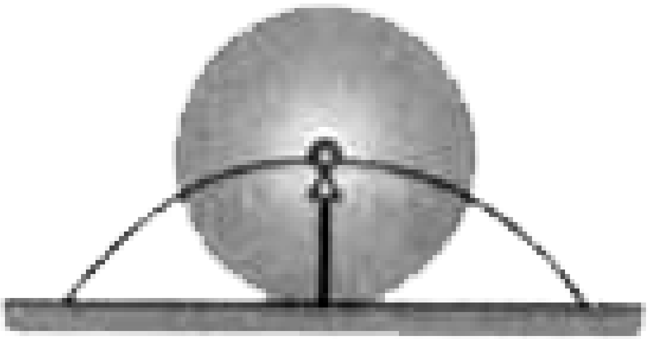

Figure 11-25 A cylinder rolling without sliding on ground.

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Example

**1.** Suggest a method to locate IC for the following situations:

(a) Given the velocity of a point on the body and the angular velocity of the body.

(b) Given the lines of action of two nonparallel velocities. (c) Given the magnitude and direction of two parallel velocities.

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Checkpoint

**1.** The rear wheel on a clown's bicycle has twice the radius of the front wheel. (a) When the bicycle is moving, is the linear speed at the very top of the rear wheel greater than, less than, or the same as that of the very top of the front wheel? (b) Is the angular speed of the rear wheel greater than, less than, or the same as that of the front wheel?

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**2.** Disks A and B are identical and roll across a floor with equal speeds. Then disk A rolls up an incline, reaching a maximum height h, and disk B moves up an incline that is identical except that it is frictionless. Is the maximum height reached by disk B greater than, less than, or equal to h?

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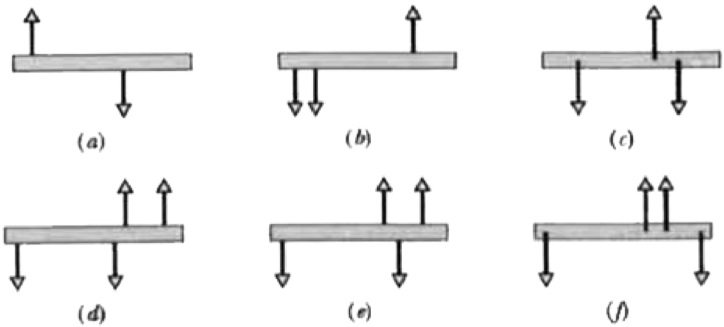
**3.** The figure gives six overhead views of a uniform rod on which two or more forces act perpendicularly to the rod. If the magnitudes of the forces are adjusted properly (but kept nonzero), in which situations can the rod be in static equilibrium?

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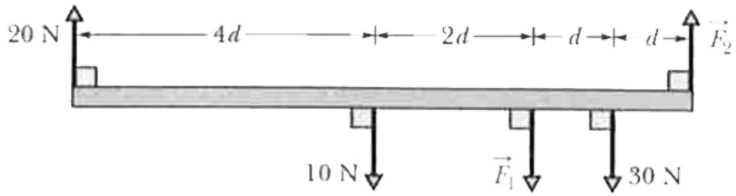
**4.** The figure gives an overhead view of a uniform rod in static equi- librium. (a) Can you find the magnitudes of unknown forces $\overrightarrow{F}_1$ and $\overrightarrow{F}_2$ by balancing the forces? (b) If you wish to find the mag nitude of force $\overrightarrow{F}_2$ by using a balance of torques equation, where should you place a rotation axis to eliminate $\vec{F}_1$ from the equation? (c) The magnitude of $\vec{F}_2$ turns out to be 65 N. What then is the magnitude of $\vec{F}_1$?

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## Problems

1. A car travels at $80 km/h$ on a level road in the positive direction of an x axis. Each tyre has a

diameter of 66 cm. Relative to a woman riding in the car and in unit-vec notation, what are the velocity $\vec{v}$ at the (a) center, (b) top, and (c) bottom of the tyre and the magnitude a of the acceleration at the (d) center, (e) top, and (f) bottom of each tyre? Relative to a hitchhiker sitting next to the road and in unit-vec notation, what are the velocity v at the (g) center, (h) top, and (i) bottom of the tyre and the magnitude a of the acceleration at the (j) center, (k) top, and (l) bottom of each tyre?

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**2.** An automobile traveling at $80.0 km / h$ has tyres of 70.0 cm diameter. (a) What is the angular speed of the tires about their axles? (b) If the car is brought to a stop uniformly in 30.0 complete turns of the tyres (without skidding), what is the magnitude of the angular accelera tion of the wheels? (c) How far does the car move during the braking?

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**3.** A solid ball of radius 6.0 cm is initially rolling smoothly at $10 m / s$ along a horizontal floor. It then rolls smoothly up a ramp until it momentarily stops. What maximum height above the floor does it reach?

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**4.** A uniform solid sphere rolls down an incline. (a) What must be the incline angle if the linear acceleration of the center of the sphere is to have a magnitude of 0.15 g? (b) If a frictionless block were to slide down the incline at that angle, would its acceleration magnitude be more than, less than or equal to 0.15 g? Why?

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**5.** From an initial height h, a solid ball rolls smoothly down one side of a U-shaped ramp and then moves up the other side, which is frictionless. What maximum height does the ball reach?

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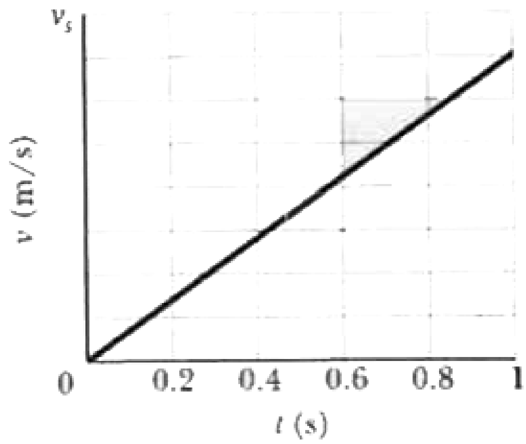
**6.** Figure gives the speed v versus time t for a 0.500 kg object of radius 5.75 cm that rolls smoothly down a $30^\circ$ ramp. The scale on the velocity axis is set by $v_s = 4.0 m/s$. What is the rotational inertia of the object?

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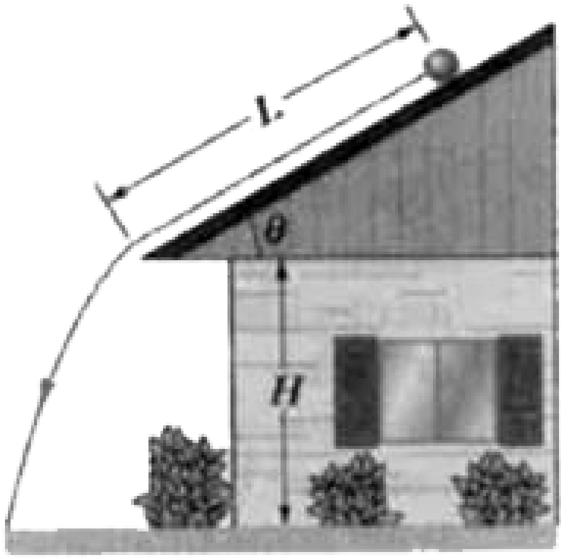
**7.** In Fig. a solid cylinder of radius 10 cm and mass 12 kg starts from rest and rolls without slipping a distance L = 6.0 m down a roof that is inclined at angle $\theta = 30^\circ$. (a) What is the angular speed of the cylinder about its center as it leaves the roof? (b)

The roof's edge is at height H = 5.0 m. How far hori zontally from the roof's edge does the cylinder hit the level ground?

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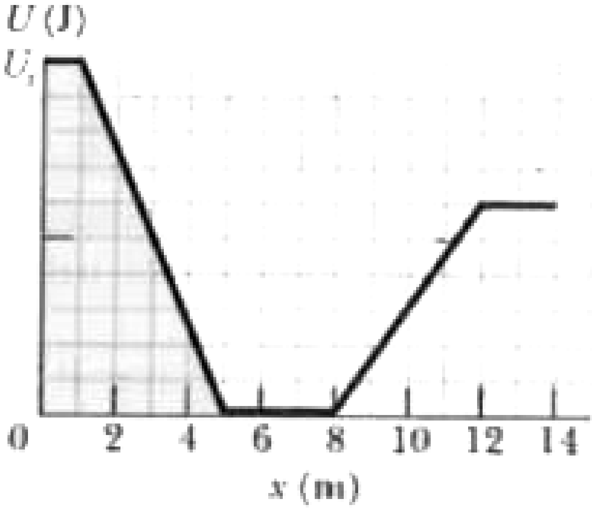
**8.** Figure shows the potential energy U(x) of a solid ball that can roll along an x axis. The scale on the U axis is set by $U_s = 100J$. The ball is uniform, rolls smoothly, and has a mass of 0.400 kg. It is released at x = 7.0 m headed in the negative direction of the x axis with a mechanical energy of 75 J. (a) If the ball can reach x = 0 m, what is its speed there, and if it cannot, what is its turning point? Suppose, instead, it is headed in the positive direction of the x axis when it is released at x = 70 m with 75 J. (b) If the ball can reach x = 13 m, what is its speed there, and if it cannot, what is its turning point?

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**9.** A hollow sphere of radius 0.15 m, with rotational inertia $I = 0.048 kg. m^2$ about a line through its center of mass, rolls without slipping up a surface inclined at $30^\circ$ to the horizontal. At a certain initial position, the sphere's total kinetic energy is 20 J. (a) How much of this initial kinetic energy is rotational? (b) What is the speed of the center of mass of the sphere at the initial position? When the sphere has moved 1.0 m up the incline from its initial position, what are (c) its total kinetic energy and (d) the speed of its center of mass?

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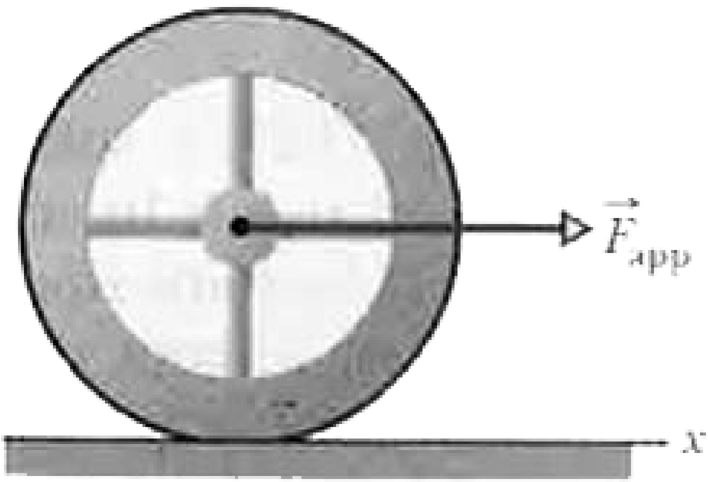
**10.** In Fig. a constant horizontal Force $\overrightarrow{F}_{\text{app}}$ of magnitude 10 N is applied to a wheel of mass 10 kg and radius 0.30 m. The wheel rolls smoothly on the horizontal surface, and the acceleration of its center $0.60 m/s^2$. (a) In unit-vec notation, what is the frictional force on the wheel? (b) What is the rotational inertia of the wheel about the rotation axis through its center of mass?

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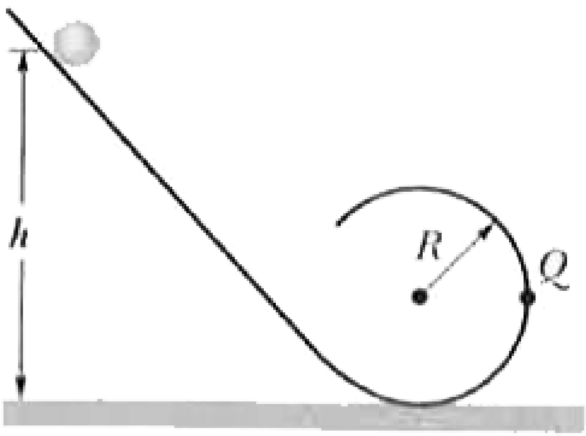
**11.** In Fig. a solid brass ball of mass 0.320 g will roll smoothly along a loop-the-loop track when released from rest along the straight section. The circular loop has radius R = 12.0 cm, and the ball has radius $r < < R$. (a) What is h if the ball is on the verge of leaving the lack when it reaches the top of the loop? If the ball is released at height h = 6.00R, what are the (b) magnitude and (c) direction of the horizontal force component acting on the ball at point Q?

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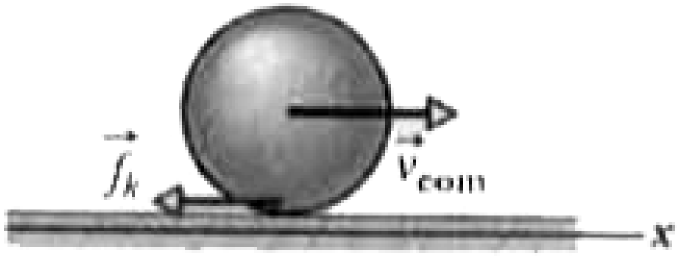
**12.** A bowler throws a bowl ing ball of radius R= 11 cm along a lane. The ball (Fig. ) slides on the lane with initial speed $v_{\text{com},0} = 8.5m/s$ and initial Th angular speed $\omega_0 = 0$. The coefficient of kinetic friction between the ball and the lane is 0.21. The kinetic frictional force $\vec{f}_k$, acting on the ball causes a linear acceleration of the ball while producing a torque that causes an angular acceleration of the ball. When speed $v_{\text{com}}$ has decreased enough and angular speed $\omega$ has increased enough, the ball stops sliding and then rolls smoothly. (a) What then is $v_{\text{com}}$ in terms of $\omega$? During the sliding, what are the ball's (b) linear acceleration and (c) angular acceleration? (d) How long does the ball slide? (e) How far does the ball slide? (f) What is the linear speed of the ball when smooth rolling begins?

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13. A yo-yo has a rotational inertia of $950 g cm^2$ and a mass of 120 g. Its axle radius is 3.2 mm, and its string is 120 cm long. The yo-yo rolls from rest down

to the end of the string. (a) What is the magnitude of its linear acceleration? (b) How long does it take to reach the end of the string? As it reaches the end of the string, what are its (c) linear speed, (d) translational kinetic energy, (e) rotational kinetic energy, and (f) angular speed?

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**14.** In 1980, over San Francisco Bay, a large yo-yo was released from a crane. The 116 kg yo-yo consisted of two uniform disks of radius 32 cm connected by an axle of radius 3.2 cm. What was the magnitude of the acceleration of the yo-yo during (a) its fall and

(b) its rise? (c) What was the tension in the cord on which it rolled? (d) Was that tension near the cord's limit of 52 kN? Suppose you build a scaled-up version of the yo-yo (same shape and mate rials but larger). (e) Will the magnitude of your yo-yo's acceleration as it falls be greater than, less than, or the same as that of the San Francisco yo-yo? (f) How about the tension in the cord?

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**15.** A thief intends to enter an apartment by climbing a ladder but foolishly places the upper end against a window. When he is 3.00 m up the ladder, the window is on the verge of shattering. His mass is 90.0 kg, the ladder's mass is 20.0 kg, the ladder's length is 5.00 m, and the foot of the ladder is 2.50 m from the base of the wall, on a non-slip ground surface. What are (a) the magnitude of the force on the glass from the ladder, (b) the magnitude of the force on the ladder from the ground, and (c) the angle between that ground force and the horizontal?

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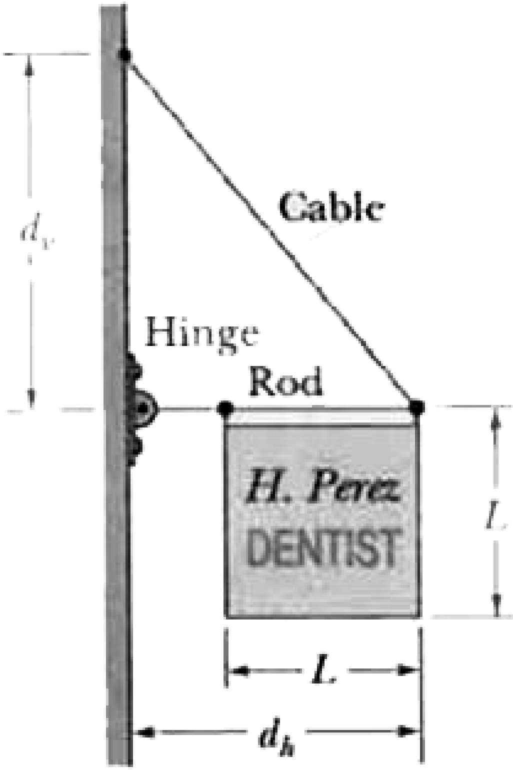
**16.** In Fig. a 50.0 kg uniform square sign, of edge length L= 2.50 m, is hung from a horizontal rod of length $d_h = 3.00m$ and negligible mass. A cable is attached to the wall. (a) What is the tension in the cable? What the end of the rod and to a point on the wall at distance $d_h = 4.00m$ above the point where the rod is hinged to the wall (a) what is the tension in the cable? What are the (b) magnitude and (c) direction (left or right) of the horizontal component of the force on the rod from the wall, and the (d) magnitude and (e) direction (up or down) of the vertical component of this force?

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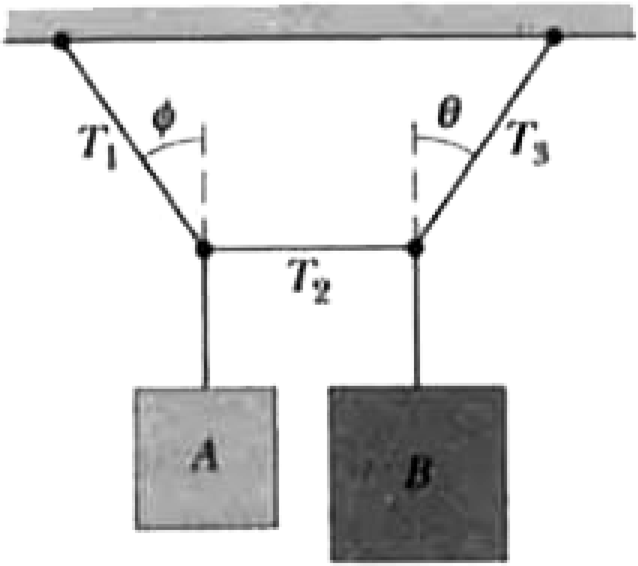
**17.** The system in Fig. is in equilibrium, with the string in the center exactly horizontal. Block A weighs 35 N, block B weighs 45 N, and angle $\phi$ is $35^{\circ}$. Find (a) tension $T_1$, (b) tension $T_2$, (c) tension $T_3$, and (d) angle $\theta$.

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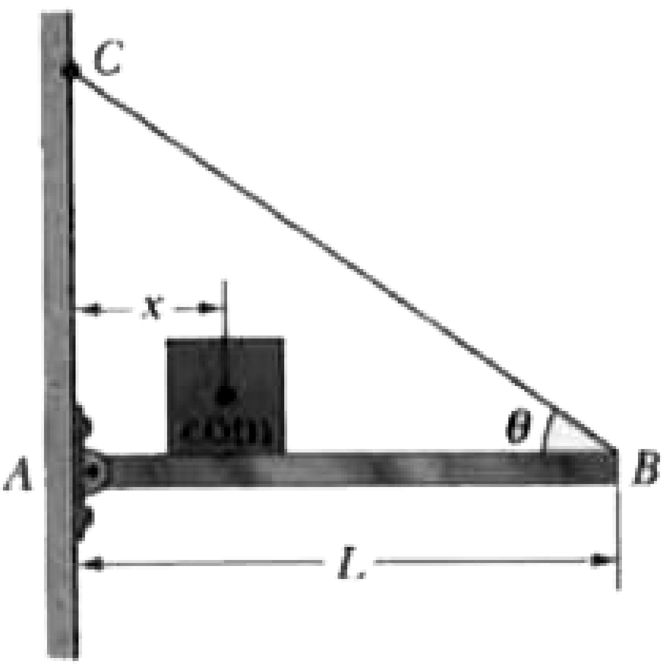
**18.** In Fig. suppose the length L of the uniform bar is 2.75 m and its weight is 185 N. Also, let the block's weight W = 300 N and the angle $\theta = 30.0^\circ$. The wire can withstand a maximum tension of 500 N. (a) What is the maximum possible distance x before the wire breaks? With the block placed at this maximum x, what are the (b) horizontal and (c) vertical components of the force on the bar from the hinge at A?



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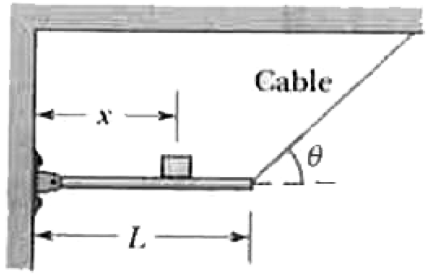
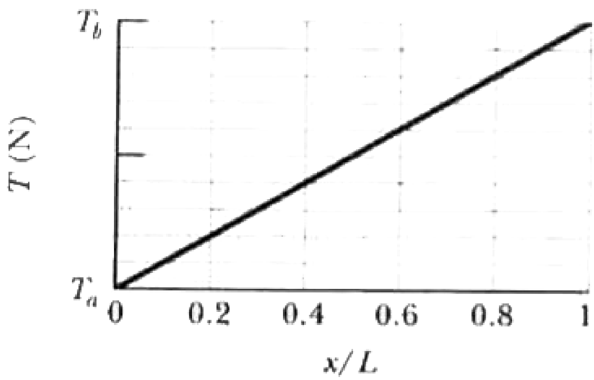
**19.** Figure shows a horizontal uniform beam of mass $m_b$, and length L that is supported on the left by a hinge attached to a wall and on the right by a cable at angle $\theta$ with the horizontal. A package of mass $m_p$ is positioned on the beam at a distance x from the left end. The total mass is $m_b + m_p = 79.30kg$. Figure gives the tension T in the cable as a function of the package's position given as a fraction $x / L$ of the beam length. The scale of the T axis is set by $T_a = 500N$ and $T_b = 700N$. Evaluate (a) angle $\theta$,

(b) mass $m_b$ and (c) mass $m_p$




(a)

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**20.** In Fig. a 25 kg block is held in place via a pulley system. The person's upper arm is vertical, the forearm is at angle $\theta = 30^\circ$ with the horizontal. Forearm and hand together have a mass of 2.0 kg, with a center of mass at distance $d_1 = 15cm$ from the contact point of the forearm bone and the upper-arm bone (humerus). The triceps muscle pulls vertically upward on the fore arm at distance $d_2 = 2.5cm$ behind that contact point. Distance $d_3$ is 35 cm. What are the (a) magnitude and (b) direction (up or down) of the force on the forearm from the triceps muscle and the (c) magnitude and (d) direction (up or down) of the force on the forearm from the humerus?

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**21.** A crate, in the form of a cube with edge lengths of 1.2 m, contains a piece of machinery, the center of mass of the crate and its contents is located 0.30 m above the crate's geometrical center. The crate rests on a ramp that makes an angle $\theta$ with the horizontal. As $\theta$ is increased from zero, an angle will be reached at which the crate will either tip over or start to slide down the ramp. If the coefficient of static friction between ramp and crate is 0.30, (a) does the crate tip or slide and (b) at what angle $\theta$ does this occur? If $\mu_s = 0.70$, (c) does the crate tip or slide and (d) at what angle $\theta$ does this occur?

(Hint: At the onset of tipping, where is the normal force located?)

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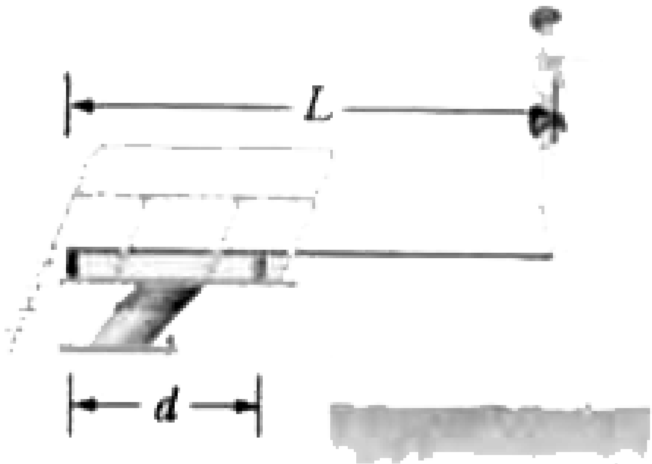
22. Figure shows a diver of weight 580 N stand ing at the end of a diving board with a length of L = 5.70 m and negligible mass. The board is fixed to two pedestals (supports) that are separated by distance d = 1.50 m. Of the forces are the (a) magnitude and (b) direction (up or down) of the force from the left ped estal and the (c) magnitude and (d) direction (up or down) of the force from the right pedestal? (e) Which pedestal (left or right) is

being stretched, and (f) which pedestal is being compressed?

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**23.** A scaffold of mass 65 kg and length 5.2 m is supported in a horizontal position by a vertical cable at each end. A window washer of mass 80 kg stands at a point 1.5 m from one end. What is the tension in (a) the nearer cable and (b) the farther cable?

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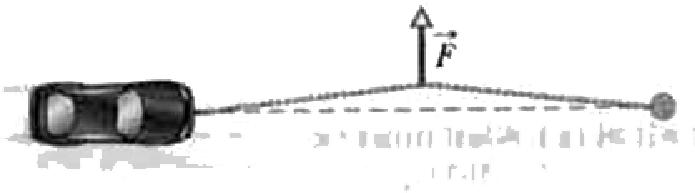
**24.** In Fig. trying to get his car out of mud, a man ties one end of a rope around the front bumper and the other end tightly around a utility pole 15 m away. He then pushes sideways on the rope at its midpoint with a force of 520 N, displacing the center of the rope 0.30 m, but the car barely moves. What is the magnitude of the force on the car from the rope? (The rope stretches somewhat.)

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**25.** A 14.0 m cord of negligible mass is stretched horizontally between two supports. When a rock climber of weight 900 N hangs from the cord's midpoint, that midpoint sags by 0.85 m. What then is the tension in the cord?

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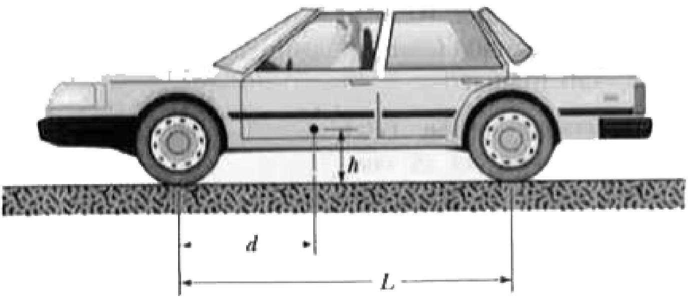
**26.** In Fig. the driver of a car on a horizontal road makes an emergency stop by applying the brakes so that all four wheels lock and skid along the road. The coefficient of kinetic friction between tires and road is 0.37. The separation between the front and rear axles is $L = 4.0$ m, and the center of mass of the car is located at distance $d = 1.9$ m behind the front axle and distance $h=0.75$ m above the road. The car weighs 11 kN. Find the magnitude of (a) the braking acceleration of the car, (b) the normal force on each rear wheel, (c) the normal force on each front wheel, (d) the braking force on each rear wheel, and (e) the braking force on each front wheel. (Hint:

Although the car is not in translational equilibrium, it is in rotational equilibrium.)

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**27.** Draw the string of a simple archery bow back at its mid point until the string tension is twice the magnitude of your force on the string. What is the angle between the two halves of the string?

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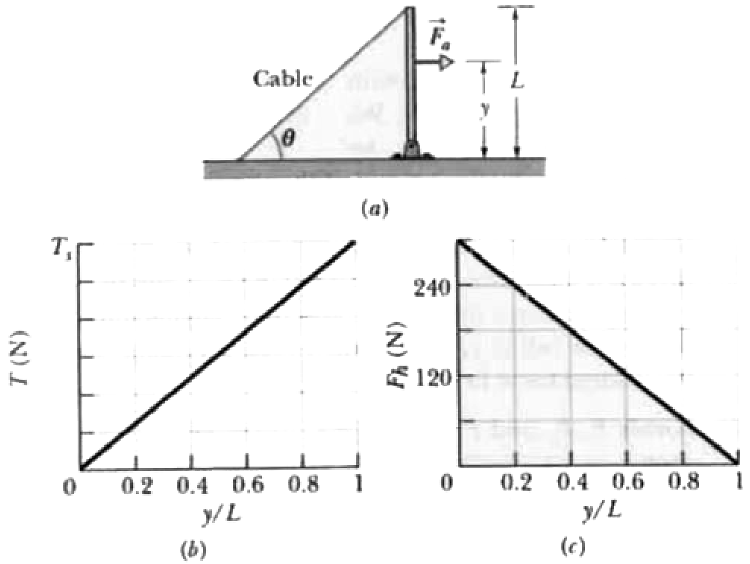
**28.** Figure shows a vertical uniform beam of length L that is hinged at its lower end. A horizontal force $\vec{F}_a$ is applied to the beam at distance y from the lower end. The beam remains vertical because of a cable attached at the upper end, at angle $\theta$ with the horizontal. Figure gives the tension T in the cable as a function of the position of the applied force given as a fraction $y/L$ of the beam length. The scale of the T axis is set by $T_s = 800N$. Figure gives the magnitude $F_h$, of the horizontal force on the beam from the hinge, also as a function of $y/L$.

Evaluate (a) angle $\theta$ and (b) the magnitude of $\vec{F}_a$

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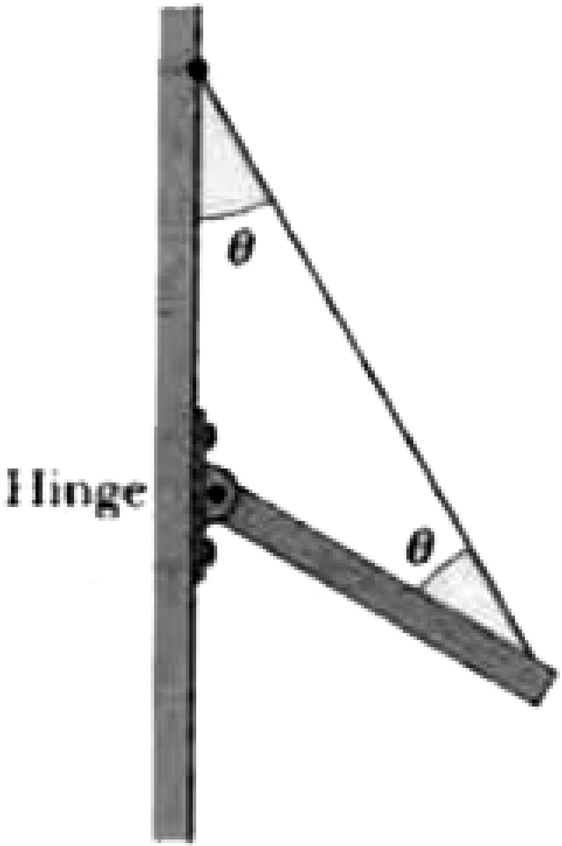
**29.** In Fig. one end of a uniform beam of mass 40.0 kg is hinged to a wall: the other end is supported by a wire that makes angles $\theta = 30.0^\circ$ with both wall and beam. Find (a) the tension in the wire and the (b) magnitude and (c) angle from the horizontal of the force of the hinge on the beam.

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**30.** A cubical box is filled with sand and weighs 520 N. We wish to "roll" the box by pushing horizontally on one of the upper edges. (a) What minimum force is required? (b) What minimum coefficient of static friction between box and floor is required? (c) If there is a more efficient way to roll the box, find the smallest possible force that would have to be applied directly to the box to roll it. (Hint: At the onset of tipping, where is the normal force located?)

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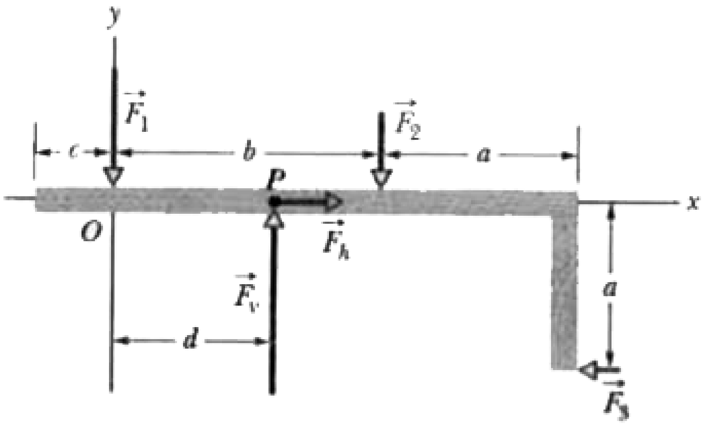
**31.** Forces $\vec{F}_1$, $\vec{F}_2$ and $\vec{F}_3$ act on the structure of Fig. shown in an overhead view. We wish to put the structure in equilibrium by applying a fourth force, at a point such as P. The fourth force has vec components $\vec{F}_h$ and $\vec{F}_v$. We are given that $a = 2.0m$, $b = 3.0m$, $c = 1.0m$, $F_1 = 30N$, $F_2 = 10N$, and $F_3 = 5.0N$. Find (a) $F_h$ (b) $F_v$ and (c) d.

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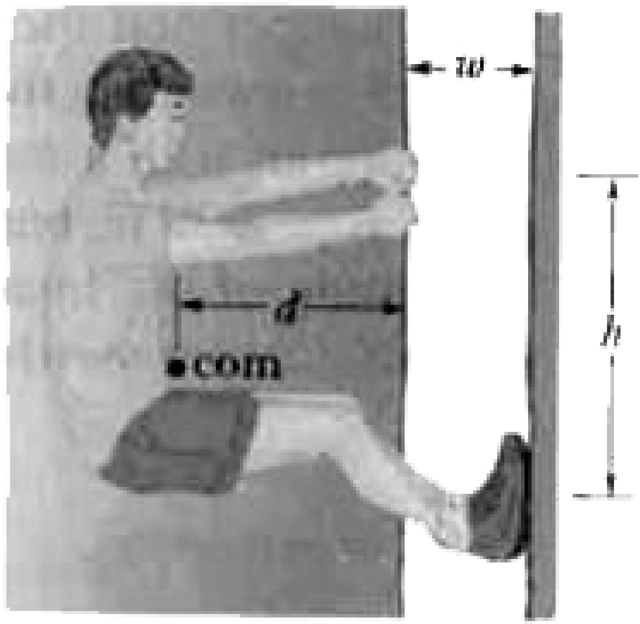
**32.** In Fig. a 55 kg rock climber is in a lie-back climb along a fissure, with hands pulling on one side of the fissure and feet pressed against the opposite side. The fissure has width = 0.20 m, and the center of mass of the climber is a horizontal distance d = 0.40 m from the fissure. The coefficient of static friction between hands and rock is $\mu_1 = 0.45$, and between boots and rock it is $\mu_2 = 1.2$. (a) What is the least horizontal pull by the hands and push by the feet that will keep the climber stable? (b) For the horizon tal pull of (a), what must be the vertical distance h between hands and feet? If the climber encounters wet rock, so that $\mu_1$ and $\mu_2$ are reduced, what happens to (c) the answer to (a) and (d) the answer to (b)?

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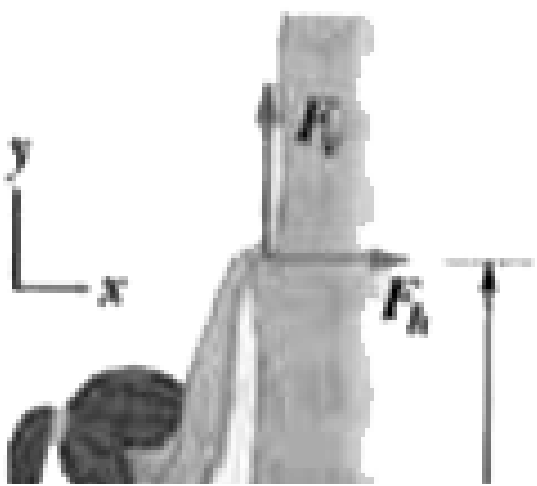
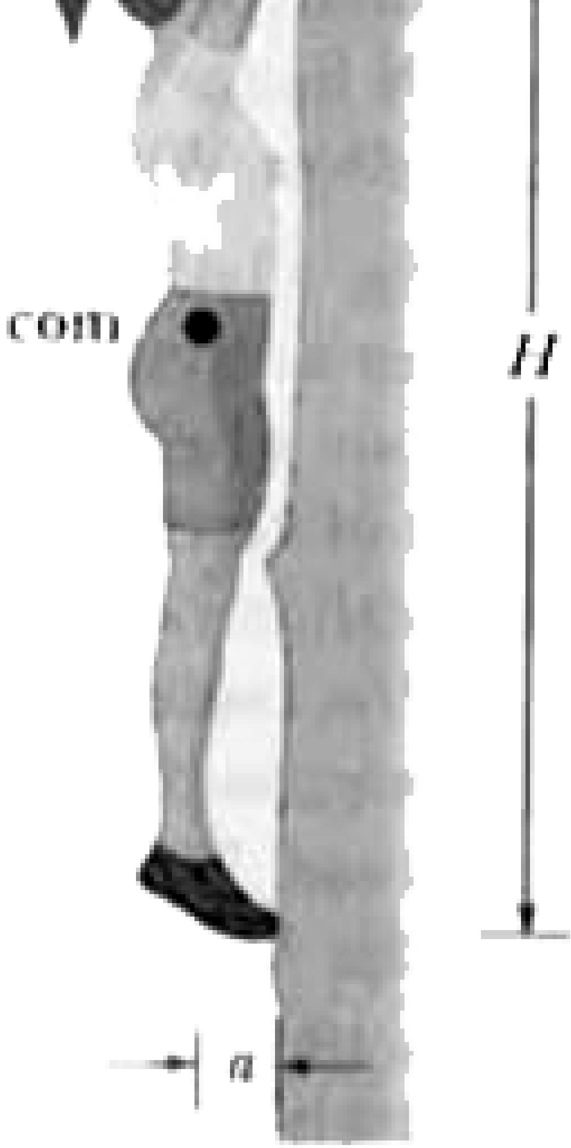
**33.** Figure shows a 75 kg climber hanging by only the crimp hold of one hand on the edge of a shallow hori zontal ledge in a rock wall. (The fingers are pressed down to gain purchase.) Her feet touch the rock wall at distance H = 2.0 m directly below her crimped fingers but do not provide any support. Her center of mass is distance a = 0.18 m from the wall. Assume that the force from the ledge supporting her fingers is equally shared by the four fingers. What are the values of the (a) hori zontal component $F_h$ and (b) vertical component $F_v$ of the force on each fingertip?



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**34.** A uniform cubical crate is 0.850 m on each side and weighs 500 N. It rests on a floor with one edge against a very small, fixed obstruction. At what least height above the floor must a horizontal force of magnitude 400 N be applied to the crate to tip it?

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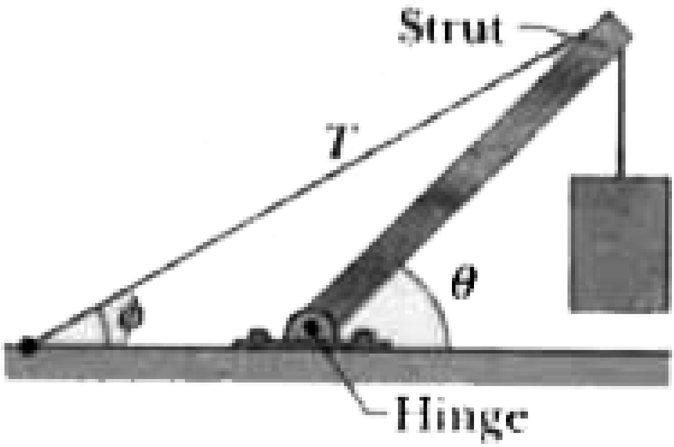
**35.** The system in Fig. is in equilibrium. A concrete block of mass 300 kg hangs from the end of the uniform strut of mass 45.0 kg. A cable runs from the ground, over the top of the strut, and down to the block, holding the block in place. For angles

$\phi = 30.0^\circ$ and $\theta = 45.0^\circ$, find (a) the ten sion T in the cable and the (b) magnitude and (c) angle (relative to the horizontal) of the force on the strut from the hinge.

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**36.** A uniform wood panel of mass 35.0 kg is hinged ver tically on a wall by two hinges, one 0.300 m from its top and the other 0.300 m from its bottom. The panel is 2.10 m tall and 0.910 m wide. A y axis extends upward through the hinges and an x axis extends outward along the panel's width. If each hinge supports half the panel's weight, what are the forces on the panel at (a) the top hinge and (b) the bottom hinge, both in unit-vec notation?

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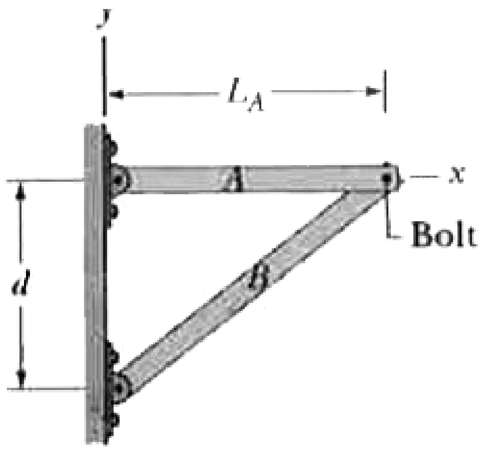
**37.** In Fig. uniform beams A and B are attached to a wall with hinges and loosely bolted together (there is no torque of one on the other). Beam A has length L = 2.40 m and mass 58.0 kg, beam B has mass 70.0 kg. The two hinge points are separated by distance d = 1.80 m. In unit-vec notation, what is the force on (a) beam A due to its hinge, (b) beam A due to the bolt, (c) beam B due to its hinge, and (d) beam B due to the bolt?



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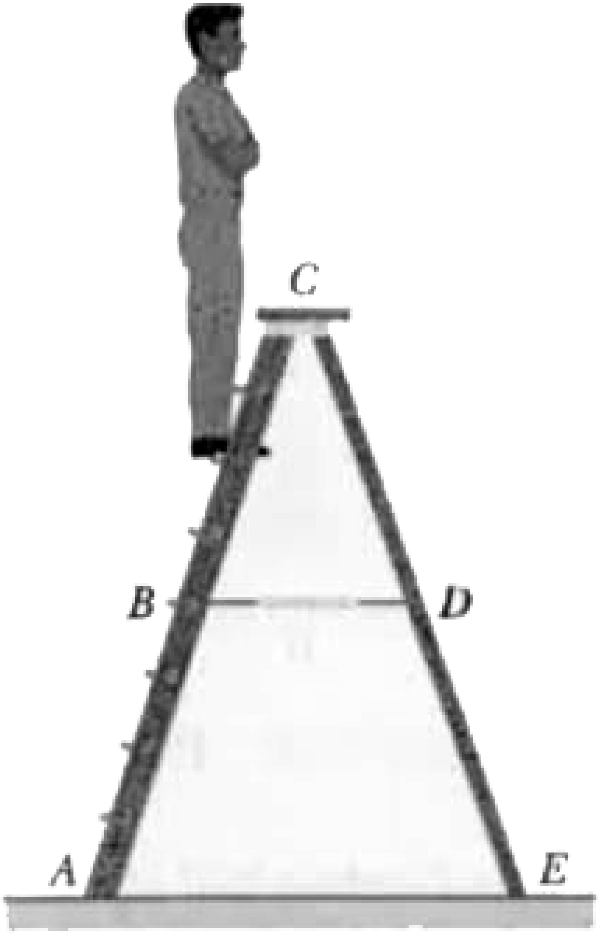
**38.** For the stepladder shown in Fig. sides AC and CE are each 2.44 m long and hinged at C. Bar BD is a tie rod 0.762 m long, halfway up. A man weighing 1045 N climbs 1.80 m along the ladder. Assuming that the floor is frictionless and neglecting the mass of the ladder, find (a) the tension in the tie-rod and the magnitudes of the forces on the ladder from the floor at (b) A and (c) E. (Hint: Isolate parts of the ladder in applying the equilibrium conditions.)

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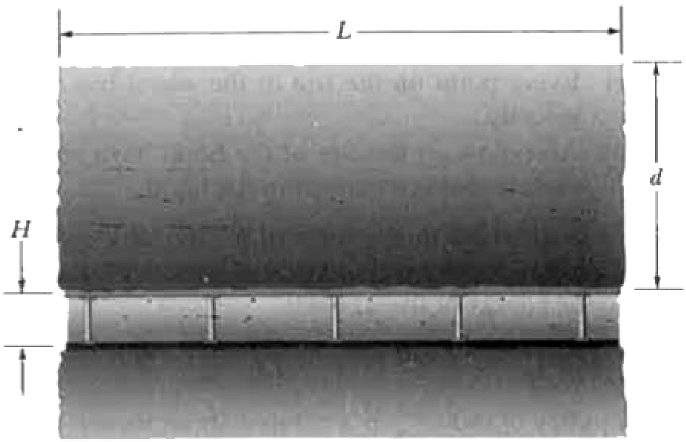
**39.** A tunnel of length L = 200 m, height H = 72 m, and width 6.3 m (with a flat roof) is to be constructed at distance d = 70 m beneath the ground (Fig). The tunnel roof is to be supported entirely by square steel columns, each with a cross-sectional area of $960 cm^2$?. The mass of $1.0 cm^3$ of the ground material is 2.8 g. (a) What is the total weight of the ground material the columns must support? (b) How many columns are needed to keep the compressive stress on each column at one-half its ultimate strength?

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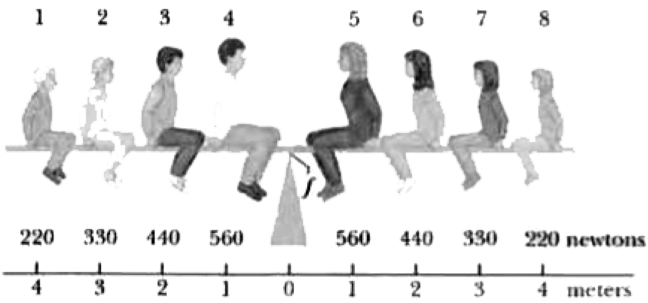
**40.** A physics Brady Bunch, whose weights in newtons are indicated in Fig. is balanced on a seesaw. What is the number of the person who causes the smallest torque about the rotation axis at fulcrum f directed (a) out of the page and (b) into the page?

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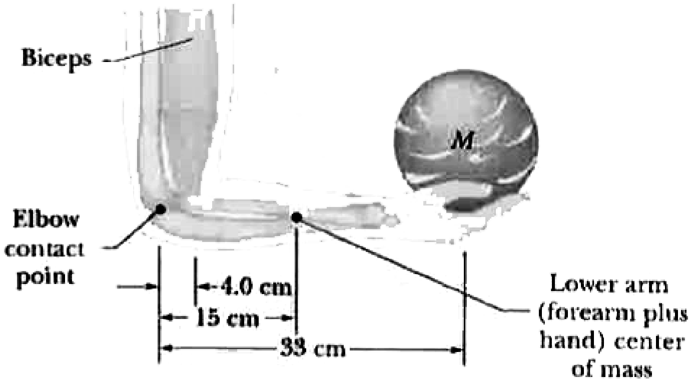
**41.** A bowler holds a bowling ball (M = 76 kg) in the palm of his hand (Fig). His upper arm is vertical, his lower arm (1.9 kg) is horizontal. What is the magnitude of (a) the force of the biceps muscle on the lower arm and (b) the force between the bony structures at the elbow contact point?

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## Practice Questions

**1.** A circular hoop rolls without slipping on a flat horizontal surface. Which one of the following is necessarily true?

A. All points on the rim of the hoop have the same speed.

B. All points on the rim of the hoop have the same velocity

C. Every point on the rim of the wheel has a different velocity

D. All of these

**Answer: C**

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**2.** A 1.0-kg wheel in the form of a solid disk rolls along a horizontal surface with a speed of $6.0m/s$. What is the total kinetic energy of the wheel?

A. 9.0 J

B. 18 J

C. 27 J

D. 36 J

**Answer: C**

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**3.** A pulley os radius 2m is rotated about its axis by a force $F=\left(20t-5t^{2}\right)$ newton (where t is measured in seconds) applied tangentially. If the moment of inertia of the pulley about its axis of rotation is $10kgm^{2}$ the number of rotaitons made by the pulley before its direction of motion is reversed, is:

A. more than 3 but less than 6.

B. more than 6 but less than 9.

C. more than 9.

D. less than 3.

**Answer: A**

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**4.** Suppose you are riding a stationary exercise bicycle, and the electronic meter indicates that the wheel is rotating at $9.1\text{rad}/s$. The wheel has a radius of 0.45 m. If you ride the bike for 35 min, how far would you have gone if the bike could move?

A. 3900 m

B. 7800 m

C. 4300 m

D. 8600 m

**Answer: D**

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**5.** Which statement concerning a wheel undergoing rolling motion is true?

A. The angular acceleration of the wheel must be zero $m / s^2$

B. The tangential velocity is the same for all points on the wheel.

C. The linear velocity for all points on the rim of the wheel is non-zero.

D. There is no slipping at the point where the wheel touches the surface on which it is rolling.

**Answer: D**

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**6.** A round uniform body of radius $R$, mass $M$ and moment of inertia 'I' rolls down (without slipping) and inclined plane making an angle $\theta$ with the horizontal. Then its acceleration is.

A. $\dfrac{g\sin\theta}{1+(I/MR^2)}$

B. $\dfrac{g\sin\theta}{1+(MR^2/I)}$

C. $\dfrac{g\sin\theta}{1-(I/MR^2)}$

D. $\dfrac{g\sin\theta}{1-(MR^2/I)}$

**Answer: A**

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**7.** A solid sphere rolls without slipping along a horizontal surface. What percentage of its total kinetic energy is rotational kinetic energy?

A. 0.33

B. 0.29

C. 0.5

D. 0.75

**Answer: B**

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**8.** An automobile tyre has a radius of 0.330 m, and its center moves forward with a linear speed of $v = 15.0 m / s$. Relative to the axle, what is the tangential speed of a point located 0.175 m from the axle?

A. $1.04 m / s$

B. $2.50 m / s$

C. $4.39 m / s$

D. $7.96 m / s$

**Answer: D**

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**9.** Two motorcycles are riding around a circular track at the same angular velocity. One motorcycle is at a radius of 15 m, and the second is at a radius of 18 m. What is the ratio of their linear speeds, $v_2 / v_1$?

A. 1

B. 1.2

C. 0.83

D. 0.71

**Answer: B**

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**10.** A bicycle has tyres of radius 0.35 meters. If the bicycle is traveling at a constant speed of $12m/s$, at approximately what angular speed are the tyres rotating?

A. $85\text{rev}/\text{min}$

B. $197\text{rev}/\text{min}$

C. $214\text{rev}/\text{min}$

D. $327\text{rev}/\text{min}$

**Answer: D**

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**11.** What happens when a spinning ice skater draws in her outstretched arms?

A. Her angular momentum decreases.

B. Her angular momentum increases.

C. Her moment of inertia decreases causing her to speed up

D. Her moment of inertia decreases causing her to slow down.

**Answer: C**

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**12.** A hollow cylinder of mass M and radius R rolls down an inclined plane. A block of mass M slides down an identical inclined plane. If both objects are released at the same time, then

A. the cylinder reaches the bottom first.

B. ) the block reaches the bottom first.

C. the block reaches the bottom with the greater kinetic energy.

D. the cylinder reaches the bottom with the greater kinetic energy

**Answer: B**

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**13.** A child standing on the edge of a freely spinning merry go-round moves quickly to the center. Which one of the following statements is necessarily true concerning this event and why?

A. The angular speed of the system decreases because the moment of inertia of the system has increased.

B. The angular speed of the system increases because the moment of inertia of the system has increased.

C. The angular speed of the system decreases because the moment of inertia of the system has decreased.

D. The angular speed of the system increases because the moment of inertia of the system has decreased.

**Answer: D**

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**14.** Two disks are rotating about the same axis. Disk A has a moment of inertia of $3.4kg - m^2$ and an angular velocity of $+72\text{rad}/s$. Disk B is rotating with an angular velocity of $-9.8\text{rad}/s$. The two disks are then linked together without the aid of any external torques, so that they rotate as a single unit with an angular velocity of $-2.4\text{rad}/s$. The axis of rotation for this unit is the same as that for the separate disks. What is the moment of inertia of disk B?

A. $4.4kg. m^2$

B. $5.2kgm^2$

C. $2.4kg. m^2$

D. $3.6kgm^2$

**Answer: A**

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**15.** A 1500 kg satellite orbits a planet in a circular orbit of radius $6.2 \times 10^6$ m. What is the angular momentum of the satellite in its orbit around the planet if the satellite completes one orbit every $1.5 \times 10^4$ s?

A. $3.9 \times 10^6 kg. m / s$

B. $2.4 \times 10^{13} kg. m / s$

C. $1.4 \times 10^{14} kg. m / s$

D. $8.1 \times 10^{11} kg. m / s$

**Answer: B**

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**16.** A solid disk rotates in the horizontal plane at an angular velocity of $0.067\mathrm{rad}/s$ with respect to an axis perpendicular to the disk at its center. The moment of inertia of the disk is $0.10kg.m^2$. From above, sand is dropped straight down onto this rotating disk, so that a thin uniform ring of sand is formed at a distance of 0.40 m from the axis. The sand in the ring has a mass of 0.50 kg. After all the sand is in place, what is the angular velocity of the disk?

A. $0.067\mathrm{rad}/s$

B. $0.046\text{rad} / s$

C. $0.059\text{rad} / s$

D. $0.037\text{rad} / s$

**Answer: D**

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**17.** A flat uniform circular disk (radius = 2.00 m, $\text{mass} = 1.00 \times 10^2$ kg) is initially stationary. The disk is free to rotate in the horizontal plane about a frictionless axis perpendic ular to the center of the disk. A 40.0-kg person, standing 1.25 m from the axis, begins to run on the disk in a circular path and has a tangential speed of $2.00m/s$ relative to the ground. Find the resulting angular speed of the disk (in $\mathrm{rad}/s$) and describe the direction of the rotation.

A. $0.500\mathrm{rad}/s$

B. $0.250\mathrm{rad}/s$

C. $2.00\mathrm{rad}/s$

D. $1.00\mathrm{rad}/s$

**Answer: A**

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**18.** A thin uniform rod is rotating at an angular velocity of $7.0 \mathrm{rad} / s$ about an axis that is perpendicular to the rod at its center. As the drawing indicates, the rod is hinged at two places, one-quarter of the length from each end. Without the aid of external torques, the rod suddenly assumes a u shape, with the arms of the u parallel to the rotation axis. What is the angular velocity of the rotating u?

A. $3.5 \mathrm{rad} / s$

B. $7.0 \mathrm{rad} / s$

C. $14 \mathrm{rad} / s$

D. $1.8 \mathrm{rad} / s$

**Answer: C**

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**19.** A small 0.500 kg object moves on a frictionless horizontal table in a circular path of radius 1.00 m. The angular speed is $6.28 \mathrm{rad} / s$. The object is attached to a string of negligible mass that passes through a small hole in the table at the center of the circle. Someone under the table begins to pull the string downward to make the circle smaller. If the string will toler ate a tension of no more than

105 N, what is the radius of the smallest possible circle on which the object can move?

A. 0.376 m

B. 0.434 m

C. 0.573 m

D. 0.188 m

**Answer: C**

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**20.** One end of a thin rod is attached to a pivot, about which it can rotate without friction. Air resistance is absent. The rod has a length of 0.80 m and is uniform. It is hanging vertically straight downward. The end of the rod nearest the floor is given a linear speed $v_0$, so that the rod begins to rotate upward about the pivot. What must be the value of $v_0$ such that the rod comes to a momentary halt in a straight-up orientation, exactly opposite to its initial orientation?

A. $6.9m\,/\,s$

B. $5.6m\,/\,s$

C. $4.7m/s$

D. $8.1m/s$

**Answer: A**

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**21.** A marble and a cube are placed at the top of a ramp. Starting from rest at the same height, the marble rolls and the cube slides (no kinetic friction) down the ramp. Determine the ratio of the center-of-mass speed of the cube to the center-of-mass speed of the marble at the bottom of the ramp.

A. 0.447

B. 1.14

C. 0.707

D. 1.18

**Answer: D**

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**22.** A particle of mass 2 kg is on a smooth horizontal table and moves in a circular path of radius 0.6 m. The height of the table from the ground is 0.8 m. If the angular speed of the particle is $12 \text{ rad s}^{-1}$, the magnitude of its angular momentum about a point on the ground right under the centre of the circle is

A. $8.64 kg. m^2 / s$

B. $11.52 kg. m^2 / s$

C. $14.4 kg. m^2 / s$

D. $20.16 kg. m^2 / s$

**Answer: B**

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**23.** Two thin rectangular sheets $(0.20m \times 0.40m)$ are identical. In the first sheet the axis of rotation lies along the 0.20-m side, and in the second it lies along the 0.40-m side. The same torque is applied to each sheet. The first sheet, starting from rest, reaches its final angular velocity in 8.0 s. How long does it take for the second sheet, starting from rest, to reach the same angular velocity?

A. 0.86 s

B. 1.4 s

C. 2.0 s

D. 1.1 s

**Answer: C**

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**24.** A disk in xy plane, initially at rest, of mass 1 kg and radius 10 m, with center at origin, can only rotate about its axis, that is, about z-axis due to a fixed axle through its center. A force $\overrightarrow{F} = \left(3\hat{i} - 4\hat{j} + \hat{k}\right)$ N starts acting on it at the point $\left(3\hat{i} + 5\hat{j}\right)$ m. The work done by the force in the first one second is

A. 2.39 J

B. 3.27 J

C. 9.27 J

D. 7.29 J

**Answer: D**

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**25.** A solid cylinder and a thin-walled hollow cylinder have the same mass and radius. They are rolling horizontally toward the bottom of an incline. The center of mass of each has the same translational speed. The cylinders roll up the incline and reach their highest points. Calculate the ratio of the distances $\left(S_{\text{Solid}} / S_{\text{hollow}}\right)$ along the incline through which each center of mass moves.

A. $\frac{4}{3}$

B. $\frac{3}{4}$

C. $\frac{2}{3}$

D. $\frac{3}{2}$

**Answer: B**

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**26.** A thin rod has a length of 0.25 m and rotates in a circle on a frictionless tabletop. The axis is perpendicular to the length of the rod at one of its ends. The rod has an angular velocity of $0.32 \mathrm{rad} / s$ and a moment of inertia of $1.1 \times 10^{-3} kg.m^2$. A bug standing on the axis decides to crawl out to the other end of the rod. When the bug $\left(\mathrm{mass} = 4.2 \times 10^{-3} kg\right)$ gets where it is going, what is the angular velocity of the rod?

A. $1.32 \mathrm{rad} / s$

B. $0.26 \mathrm{rad} / s$

C. $0.93 \mathrm{rad} / s$

D. $1.66\text{rad}/s$

**Answer: B**

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**27.** A small 0.500 kg object moves on a frictionless horizontal table in a circular path of radius 1.00 m. The angular speed is $6.28\text{rad}/s$. The object is attached to a string of negligible mass that passes through a small hole in the table at the center of the circle. Someone under the table begins to pull the string downward to make the circle smaller. If the string will tolerate a tension of no more than

105 N, what is the radius of the smallest possible circle on which the object can move?

A. 0.376 m

B. 0.434 m

C. 0.573 m

D. 0.659 m

**Answer: C**

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**28.** A ball of radius r is rolling (pure rolling) on a convex stationary circular surface of radius R with angular velocity $\omega$ and angular acceleration $\alpha$. The magnitude of vertical acceleration of top point of the ball is

A. $\omega^2 r\left(\frac{R+2r}{R+r}\right)$

B. $\omega^2 r$

C. $\frac{\omega^2 r}{R+r}$

D. $\frac{\omega^2 r R}{R+r}$

**Answer: A**

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## Practice Questions More Than One Option Correct Type

**1.** A ring $(R)$, a disc $(D)$, a solid sphere $(S)$ and a hollow sphere with thin walls $(H)$, all having the same mass but different radii, start together from rest at the top of inclined plane and roll down without slipping. Then

A. all of them will reach the bottom of the incline together.

B. the body with the maximum radius will reach the bottom first.

C. they will reach the bottom in the order S, D, H and R.

D. all of them will have the same kinetic energy at the bottom of the incline.

**Answer: C::D**

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**2.** A body moves on a straight line with a uniform velocity Its angular momentum

A. is zero about a point on the straight line.

B. remains constant about any given point.

C. is always zero.

D. is not zero about a point away from the straight line.

**Answer: A::B::C**

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## Practice Questions Linked Comprehension

**1.** Two discs A and B are mounted coaxiallay on a vertical axle. The discs have moments of inertia I and 2 I respectively about the common axis. Disc A is imparted an initial angular velocity $2\omega$ using the entire potential energy of a spring compressed by a distance $x_1$ Disc B is imparted an angular velocity $\omega$ by a spring having the same spring constant and compressed by a distance $x_2$ Both the discs rotate in the clockwise direction.

The ratio $x_1 / x_2$ is

A. 2

B. $\frac{1}{2}$

C. $\sqrt{2}$

D. $\frac{1}{\sqrt{2}}$

**Answer: C**

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**2.** Two discs A and B are mounted coaxiallay on a vertical axle. The discs have moments of inertia I and 2 I respectively about the common axis. Disc A is imparted an initial angular velocity $2\omega$ using the entire potential energy of a spring compressed by a distance $x_1$ Disc B is imparted an angular velocity $\omega$ by a spring having the same spring constant and compressed by a distance $x_2$ Both the discs rotate in the clockwise direction.

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. $\frac{3I\omega}{2t}$

**Answer: A**

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**3.** Two discs $A$ and $B$ are mounted coaxially ona vertical axle. The discs have moments of inertia $l$ and $2l$ respectively about the common axis. Disc A is imparted an initial angular velocity $2\omega$ using the centre potential energy of a spring compressed by a distance $x_1$. Disc $B$ is imparted angular velocity $\omega$ by a spring having the same spring constant and compressed by a distance $x_2$. Both the disc rotate in the clockwise direction.

The loss of kinetic energy the above process is -

A. $\frac{-I\omega^2}{2}$

B. $\frac{-I\omega^2}{3}$

C. $\frac{-I\omega^2}{4}$

D. $\frac{-I\omega^2}{6}$

**Answer: B**

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## Practice Questions Matrix Match

**1.** Match the statement in Column I with the statements in Column II. One or more than one choice from Column II can match with a statement from Column I.

| **Column I** | **Column II** |
|---|---|
| **(a)** For a wheel of radius $R$ rolling smoothly, | **(p)** $\vec{F}_{net} = 0$ |
| **(b)** If a wheel is being accelerated but is still rolling smoothly, | **(q)** $a_{com,x} = -\dfrac{g\sin\theta}{1 + I_{com}/MR^2}$ |
| **(c)** If the wheel rolls smoothly down a ramp, its acceleration is | **(r)** $a_{com} = \alpha R$ |
| **(d)** For a body at static equilibrium, the vector sum of the external forces acting on it is | **(s)** $v_{com} = \omega R$ |

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**2.** In the given table, Column I gives mass of a rotating cylinder, Column II gives its radius and Column III gives the angular speed.

| Column I | Column II | Column III |
|---|---|---|
| (I) Mass of cylinder ($m$) rotating as pully is 23 kg | (i) The radius of cylinder ($r$) is 0.4 m | (J) The angular speed ($\omega$) of the cylinder is 3.4 rad/s |
| (II) Mass of cylinder ($m$) rotating as pully is 20 kg | (ii) The radius of cylinder ($r$) is 0.5 m | (K) The angular speed ($\omega$) of the cylinder is 4.1 rad/s |

| Column I | Column II | Column III |
|---|---|---|
| (III) Mass of cylinder ($m$) rotating as pully is 22.2 kg | (iii) The radius of cylinder ($r$) is 0.2 m | (L) The angular speed ($\omega$) of the cylinder is 4 rad/s |
| (IV) Mass of cylinder ($m$) rotating as pully is 17 kg | (iv) The radius of cylinder ($r$) is 0.1 m | (M) The angular speed ($\omega$) of the cylinder is 4.5 rad/s |

The combination whose rotational kinetic energy that equals 3.2 J is

A. (I) (ii) (J)

B. (II) (iii) (L)

C. (II) (i) (M)

D. (I) (ii) (M)

**Answer:**

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**3.** In the given table, Column I gives mass of a rotating cylinder, Column II gives its radius and Column III gives the angular speed.

| Column I | Column II | Column III |
|---|---|---|
| (I) Mass of cylinder ($m$) rotating as pully is 23 kg | (i) The radius of cylinder ($r$) is 0.4 m | (J) The angular speed ($\omega$) of the cylinder is 3.4 rad/s |
| (II) Mass of cylinder ($m$) rotating as pully is 20 kg | (ii) The radius of cylinder ($r$) is 0.5 m | (K) The angular speed ($\omega$) of the cylinder is 4.1 rad/s |

| Column I | Column II | Column III |
|---|---|---|
| (III) Mass of cylinder ($m$) rotating as pully is 22.2 kg | (iii) The radius of cylinder ($r$) is 0.2 m | (L) The angular speed ($\omega$) of the cylinder is 4 rad/s |
| (IV) Mass of cylinder ($m$) rotating as pully is 17 kg | (iv) The radius of cylinder ($r$) is 0.1 m | (M) The angular speed ($\omega$) of the cylinder is 4.5 rad/s |

The combination whose rotational kinetic energy that equals 16.6 J is

A. (I) (iii) (K)

B. (IV) (iii) (L)

C. (II) (iii) (L)

D. (I) (ii) (J)

**Answer:**

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**4.** In the given table, Column I gives mass of a rotating cylinder, Column II gives its radius and Column III gives the angular speed.

| Column I | Column II | Column III |
|---|---|---|
| **(I)** Mass of cylinder ($m$) rotating as pully is 23 kg | **(i)** The radius of cylinder ($r$) is 0.4 m | **(J)** The angular speed ($\omega$) of the cylinder is 3.4 rad/s |
| **(II)** Mass of cylinder ($m$) rotating as pully is 20 kg | **(ii)** The radius of cylinder ($r$) is 0.5 m | **(K)** The angular speed ($\omega$) of the cylinder is 4.1 rad/s |

| Column I | Column II | Column III |
|---|---|---|
| **(III)** Mass of cylinder ($m$) rotating as pully is 22.2 kg | **(iii)** The radius of cylinder ($r$) is 0.2 m | **(L)** The angular speed ($\omega$) of the cylinder is 4 rad/s |
| **(IV)** Mass of cylinder ($m$) rotating as pully is 17 kg | **(iv)** The radius of cylinder ($r$) is 0.1 m | **(M)** The angular speed ($\omega$) of the cylinder is 4.5 rad/s |

The combination whose rotational kinetic energy that equals 1.72 J is

A. (III) (i) (K)

B. (I) (i) (L)

C. (IV) (i) (M)

D. (II) (ii) (M)

**Answer:**

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**5.** In the given table, Column I denotes the mass of the cylindrical shell, Column II refers to the radius of the shell and Column III refers to its length.

| Column I | Column II | Column III |
|---|---|---|
| (I) 2 kg | (i) 2 m | (J) 6 m |
| (II) 14 kg | (ii) 4 m | (K) 1 m |
| (III) 6 kg | (iii) 3 m | (L) 7 m |
| (IV) 12 kg | (iv) 5 m | (M) 10 m |

Find the combination that results in $348 kg.m^2$ as rotational inertia.

A. (I) (ii) (L)

B. (IV) (i) (M)

C. (II) (iv) (K)

D. (III) (ii) (M)

**Answer:**

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**6.** In the given table, Column I denotes the mass of the cylindrical shell, Column II refers to the radius of the shell and Column III refers to its length.

| Column I | Column II | Column III |
|---|---|---|
| (I) 2 kg | (i) 2 m | (J) 6 m |
| (II) 14 kg | (ii) 4 m | (K) 1 m |
| (III) 6 kg | (iii) 3 m | (L) 7 m |
| (IV) 12 kg | (iv) 5 m | (M) 10 m |

Find the combination that results in $270kg.m^2$? as rota tional inertia.

A. (III) (ii) (L)

B. (IV) (iii) (J)

C. (II) (iii) (K)

D. (I) (i) (M)

**Answer:**

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**7.** In the given table, Column I denotes the mass of the cylindrical shell, Column II refers to the radius of the shell and Column III refers to its length.

| Column I | Column II | Column III |
|---|---|---|
| (I) 2 kg | (i) 2 m | (J) 6 m |
| (II) 14 kg | (ii) 4 m | (K) 1 m |
| (III) 6 kg | (iii) 3 m | (L) 7 m |
| (IV) 12 kg | (iv) 5 m | (M) 10 m |

Find the combination that results in $371 kg. m^2$ as rotational inertia.

A. (II) (i) (L)

B. (I) (i) (K)

C. (III) (iii) (L)

D. (I) (ii) (L)

**Answer:**

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## Practice Questions Integer Type

**1.** A uniform circular disc of mass 50kg and radius 0.4 m is rotating with an angular velocity of $10rads^{-1}$ 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 $( \in reds^{-1})$ of the system is

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2. A binary star consists of two stars $A(mass 2.2 M_s)$ and B $(mass 11 M_s)$ where $M_s$ is the mass of the sun, they are separted by distane d and are rotating about their center of mass, which is stationary. The ratio of the total angular momentum of the binary to the angular momentum of star B about the centre of mass is

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