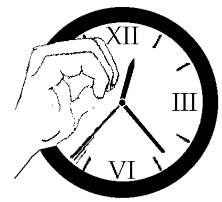
CHAPTER 10

ANSWERS TO QUESTIONS

Q10.1 For an assumed constant force, the torque $\mathbf{r}\times\mathbf{F}$ decreases with time as r decreases. The angular speed increases as r decreases. A break is most likely with a nearly empty reel, where the tape tension increases rapidly as the tape accelerates to high angular speed.

Q10.2 The speedometer will be inaccurate. The speedometer measures the number of revolutions per second of the tires. A larger tire will travel more distance in one full revolution as $2\pi r$.

Q10.3 1 rpm, or $(\pi/30)$ rad/s. Into the wall (clockwise rotation). $\alpha = 0$



Q10.4 No. Only if its angular momentum changes.

Q10.5 No horizontal force acts on the pencil, so its center of mass moves straight down.

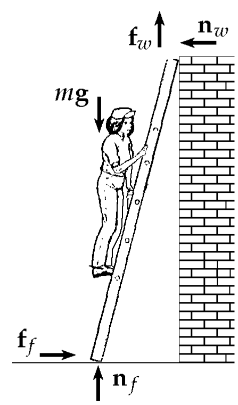
Q10.6 To balance the torques. If it had only one rotor, the engine would cause the body of the helicopter to swing around rapidly with angular momentum opposite to the rotor.

Q10.7 Suppose we look at the motorcycle moving to the right. Its drive wheel is turning clockwise. The wheel speeds up when it leaves the ground. No outside torque about its center of mass acts on the airborne cycle, so its angular momentum is conserved. As the drive wheel's clockwise angular momentum increases, the frame of the cycle acquires counterclockwise angular momentum. The cycle's front end moves up and its back end moves down.

Q10.8 Compared to an axis through the CM, any other parallel axis will have larger average squared distance from the axis to the particles of which the object is composed.

Q10.9 The hard–boiled egg. Its mass is more concentrated toward the center. Also, the raw egg loses energy to internal fluid friction.

Q10.10 It is necessary to have friction on the floor to keep the base of the ladder from sliding.



Q10.11 The diver leaves the platform with some angular momentum about a horizontal axis through her center of mass. When she draws up her legs, her moment of inertia decreases and her angular speed increases for conservation of angular momentum. Straightening out again slows her rotation.

Q10.12 Forces that add to zero can produce a nonzero total torque. Consider pushing up with one hand on one side of a steering wheel and pulling down equally hard with the other hand on the other side. A pair of equal-magnitude oppositely-directed forces applied at different points is called a couple.

Q10.13 The long pole has a large moment of inertia about an axis along the rope. An unbalanced torque will then produce only a small angular acceleration of the performer-pole system, to extend the time available for getting back in balance. To keep the center of mass above the rope, the performer can shift the pole left or right, instead of having to bend his body around. The pole sags down at the ends to lower the system center of gravity.

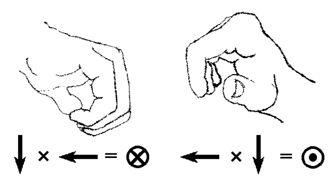
Q10.14 Try it first and then explain it! If there is no air resistance and no rolling resistance, Example 10.15 shows that the races will be ties. The race results can reveal a small amount of air resistance.

Q10.15 You want small, solid, light wheels. These choices will minimize the moment of inertia of the wheels and the rotational kinetic energy they acquire. Then a greater share of the original gravitational energy is available as translational kinetic energy for the racer.

Q10.16 The second trial requires more work. According to the parallel axis theorem, the hoop has a larger moment of inertia about the axis, through *P*, that does not go through its center of mass.

Q10.17 (a) Down–cross–left is away from you: $-\mathbf{j}\times(-\mathbf{i}) = -\mathbf{k}$

(b) Left–cross–down is toward you: $-\mathbf{i}\times(-\mathbf{j}) = \mathbf{k}$



Q10.18 Mass moves away from axis of rotation, so moment of inertia increases, angular speed decreases, and period increases.

PROBLEM SOLUTIONS

10.1 $\omega_i = \frac{100 \text{ rev}}{1.00 \text{ min}}\left(\frac{1 \text{ min}}{60.0 \text{ s}}\right)\left(\frac{2\pi \text{ rad}}{1.00 \text{ rev}}\right) = \frac{10\pi}{3} \text{ rad/s}, \ \omega_f = 0$

(a) $t = \frac{\omega_f - \omega_i}{\alpha} = \frac{0 - 10\pi/3}{-2.00} \text{ s} = \boxed{5.24 \text{ s}}$

(b) $\theta_f = \bar{\omega} t = \left(\frac{\omega_f + \omega_i}{2}\right)t = \left(\frac{10\pi}{6} \text{ rad/s}\right)\left(\frac{10\pi}{6} \text{ s}\right) = \boxed{27.4 \text{ rad}}$

10.2 $\omega_i = 2000 \text{ rad/s}, \ \alpha = -80.0 \text{ rad/s}^2$

(a) $\omega_f = \omega_i + \alpha t = 2000 - (80.0)(10.0) = \boxed{1200 \text{ rad/s}}$

(b) $0 = \omega_i + \alpha t$

$t = \frac{\omega_i}{-\alpha} = \frac{2000}{80.0} = \boxed{25.0 \text{ s}}$

10.3 $\omega_f = 2.51 \times 10^4 \text{ rev/min} = 2.63 \times 10^3 \text{ rad/s}$

(a) $\alpha = \frac{\omega_f - \omega_i}{t} = \frac{2.63 \times 10^3 \text{ rad/s} - 0}{3.2 \text{ s}} = \boxed{8.22 \times 10^2 \text{ rad/s}^2}$

(b) $\theta_f = \omega_i t + \frac{1}{2}\alpha t^2 = 0 + \frac{1}{2}\left(8.22 \times 10^2 \text{ rad/s}^2\right)(3.2 \text{ s})^2 = \boxed{4.21 \times 10^3 \text{ rad}}$

10.4 (a) $\theta|_{t=0} = \boxed{5.00 \text{ rad}}$

$\omega|_{t=0} = \left.\frac{d\theta}{dt}\right|_{t=0} = 10.0 + 4.00t|_{t=0} = \boxed{10.0 \text{ rad/s}}$

$\alpha_{t=0} = \left.\frac{d\omega}{dt}\right|_{t=0} = \boxed{4.00 \text{ rad/s}^2}$

(b) $\theta|_{t=3.00 \text{ s}} = 5.00 + 30.0 + 18.0 = \boxed{53.0 \text{ rad}}$

$\omega|_{t=3.00 \text{ s}} = \left.\frac{d\theta}{dt}\right|_{t=3.00 \text{ s}} = 10.0 + 4.00t|_{t=3.00 \text{ s}} = \boxed{22.0 \text{ rad/s}}$

$\alpha|_{t=3.00 \text{ s}} = \left.\frac{d\omega}{dt}\right|_{t=3.00 \text{ s}} = \boxed{4.00 \text{ rad/s}^2}$

10.5 $\omega = 5.00\text{ rev/s} = 10.0\pi\text{ rad/s}$. We will break the motion into two stages: (1) a period during which the tub speeds up and (2) a period during which it slows down.

While speeding up, $\theta_1 = \bar{\omega} t = \dfrac{0 + 10.0\pi\text{ rad/s}}{2}(8.00\text{ s}) = 40.0\pi\text{ rad}$

While slowing down, $\theta_2 = \bar{\omega} t = \dfrac{10.0\pi\text{ rad/s} + 0}{2}(12.0\text{ s}) = 60.0\pi\text{ rad}$

So, $\theta_{\text{total}} = \theta_1 + \theta_2 = 100\pi\text{ rad} = \boxed{50.0\text{ rev}}$

10.6 $\theta_f - \theta_i = \omega_i t + \frac{1}{2}\alpha t^2$ and $\omega_f = \omega_i + \alpha t$ are two equations in two unknowns ω_i and α

$\omega_i = \omega_f - \alpha t$: $\theta_f - \theta_i = (\omega_f - \alpha t)t + \frac{1}{2}\alpha t^2 = \omega_f t - \frac{1}{2}\alpha t^2$

$37.0\text{ rev}(2\pi\text{ rad}/1\text{ rev}) = 98.0\text{ rad/s}(3.00\text{ s}) - \frac{1}{2}\alpha(3.00\text{ s})^2$

$232\text{ rad} = 294\text{ rad} - (4.50\text{ s}^2)\alpha$: $\alpha = \dfrac{61.5\text{ rad}}{4.50\text{ s}^2} = \boxed{13.7\text{ rad/s}^2}$

***10.7** (a) $\omega = \dfrac{\Delta\theta}{\Delta t} = \dfrac{1\text{ rev}}{1\text{ day}} = \dfrac{2\pi\text{ rad}}{86\,400\text{ s}} = \boxed{7.27 \times 10^{-5}\text{ rad/s}}$

(b) $\Delta t = \dfrac{\Delta\theta}{\omega} = \dfrac{107°}{7.27 \times 10^{-5}\text{ rad/s}}\left(\dfrac{2\pi\text{ rad}}{360°}\right) = \boxed{2.57 \times 10^4\text{ s}}$ or 428 min

***10.8** Estimate the tire's radius at 0.250 m and miles driven as 10000 per year.

$\theta = \dfrac{s}{r} = \dfrac{1.00 \times 10^4\text{ mi}}{0.250\text{ m}}\left(\dfrac{1609\text{ m}}{1\text{ mi}}\right) = 6.44 \times 10^7\text{ rad/yr}$

$\theta = 6.44 \times 10^7\text{ rad/yr}\left(\dfrac{1\text{ rev}}{2\pi\text{ rad}}\right) = 1.02 \times 10^7\text{ rev/yr}$ or $\boxed{\sim 10^7\text{ rev/yr}}$

10.9 (a) $\omega = 2\pi f = \dfrac{2\pi\text{ rad}}{1\text{ rev}}\left(\dfrac{1200\text{ rev}}{60.0\text{ s}}\right) = \boxed{126\text{ rad/s}}$

(b) $v = \omega r = (126\text{ rad/s})(3.00 \times 10^{-2}\text{ m}) = \boxed{3.77\text{ m/s}}$

(c) $a_c = \omega^2 r = (126)^2(8.00 \times 10^{-2}) = 1260\text{ m/s}^2$ so $\mathbf{a}_r = \boxed{1.26\text{ km/s}^2\text{ toward the center}}$

(d) $s = r\theta = \omega r t = (126\text{ rad/s})(8.00 \times 10^{-2}\text{ m})(2.00\text{ s}) = \boxed{20.1\text{ m}}$

***10.10** (a) $\omega_i = \frac{v}{r} = \frac{1.30\text{ m/s}}{0.023\text{ m}} = \boxed{56.5\text{ rad/s}}$

(b) $\omega_f = \frac{1.30\text{ m/s}}{0.058\text{ m}} = \boxed{22.4\text{ rad/s}}$

(c) $\omega_f = \omega_i + \alpha t:$ $\alpha = \frac{22.4\text{ rad/s} - 56.5\text{ rad/s}}{\left(74(60)+33\right)\text{ s}} = \frac{-34.1\text{ rad/s}}{4473\text{ s}} = \boxed{-7.63\times10^{-3}\text{ rad/s}^2}$

(d) $\theta_f - \theta_i = \frac{1}{2}\left(\omega_f + \omega_i\right)t = \frac{1}{2}\left((56.5+22.4)\text{ rad/s}\right)(4473\text{ s}) = \boxed{1.77\times10^5\text{ rad}}$

(e) $x = vt = (1.30\text{ m/s})(4473\text{ s}) = \boxed{5.81\times10^3\text{ m}}$

10.11 (a) $s = \bar{v}t = (11.0\text{ m/s})(9.00\text{ s}) = 99.0\text{ m}$

$\theta = \frac{s}{r} = \frac{99.0\text{ m}}{0.290\text{ m}} = 341\text{ rad} = \boxed{54.3\text{ rev}}$

(b) $\omega_f = \frac{v_f}{r} = \frac{22.0\text{ m/s}}{0.290\text{ m}} = 75.9\text{ rad/s} = \boxed{12.1\text{ rev/s}}$

***10.12** Given $r = 1.00\text{ m}$, $\alpha = 4.00\text{ rad/s}^2$, $\omega_i = 0$, and $\theta_i = 57.3° = 1.00\text{ rad}$

(a) $\omega_f = \omega_i + \alpha t = 0 + \alpha t$

At $t = 2.00\text{ s}$, $\omega_f = 4.00\text{ rad/s}^2(2.00\text{ s}) = \boxed{8.00\text{ rad/s}}$

(b) $v = r\omega = 1.00\text{ m}(8.00\text{ rad/s}) = \boxed{8.00\text{ m/s}}$

$|a_r| = a_c = r\omega^2 = 1.00\text{ m}(8.00\text{ rad/s})^2 = 64.0\text{ m/s}^2$

$a_t = r\alpha = 1.00\text{ m}\left(4.00\text{ rad/s}^2\right) = 4.00\text{ m/s}^2$

The magnitude of the total acceleration is:

$a = \sqrt{a_r^2 + a_t^2} = \sqrt{\left(64.0\text{ m/s}^2\right)^2 + \left(4.00\text{ m/s}^2\right)^2} = \boxed{64.1\text{ m/s}^2}$

The direction of the total acceleration vector makes an angle ϕ with respect to the radius to point P:

$\phi = \tan^{-1}\left(\frac{a_t}{a_c}\right) = \tan^{-1}\left(\frac{4.00}{6.00}\right) = \boxed{3.58°}$

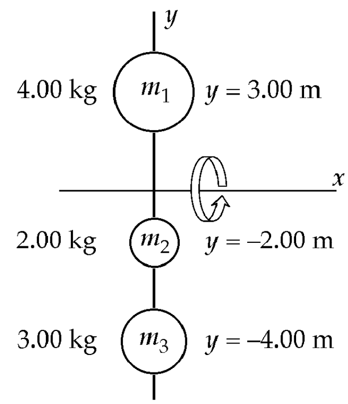
(c) $\theta_f = \theta_i + \omega_i t + \frac{1}{2}\alpha t^2 = (1.00\text{ rad}) + \frac{1}{2}\left(4.00\text{ rad/s}^2\right)(2.00\text{ s})^2 = \boxed{9.00\text{ rad}}$

10.13 $m_1 = 4.00 \text{ kg},\ r_1 = |y_1| = 3.00 \text{ m};$

$m_2 = 2.00 \text{ kg},\ r_2 = |y_2| = 2.00 \text{ m};$

$m_3 = 3.00 \text{ kg},\ r_3 = |y_3| = 4.00 \text{ m};$

$\omega = 2.00 \text{ rad/s}$ about the x-axis



(a) $I_x = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2$

$$I_x = 4.00(3.00)^2 + 2.00(2.00)^2 + 3.00(4.00)^2 = \boxed{92.0 \text{ kg} \cdot \text{m}^2}$$

$$K_R = \tfrac{1}{2} I_x \omega^2 = \tfrac{1}{2}(92.0)(2.00)^2 = \boxed{184 \text{ J}}$$

(b) $v_1 = r_1\omega = 3.00(2.00) = \boxed{6.00 \text{ m/s}}$ $\quad K_1 = \tfrac{1}{2} m_1 v_1^2 = \tfrac{1}{2}(4.00)(6.00)^2 = 72.0 \text{ J}$

$v_2 = r_2\omega = 2.00(2.00) = \boxed{4.00 \text{ m/s}}$ $\quad K_2 = \tfrac{1}{2} m_2 v_2^2 = \tfrac{1}{2}(2.00)(4.00)^2 = 16.0 \text{ J}$

$v_3 = r_3\omega = 4.00(2.00) = \boxed{8.00 \text{ m/s}}$ $\quad K_3 = \tfrac{1}{2} m_3 v_3^2 = \tfrac{1}{2}(3.00)(8.00)^2 = 96.0 \text{ J}$

$$K = K_1 + K_2 + K_3 = 72.0 + 16.0 + 96.0 = \boxed{184 \text{ J}} = \tfrac{1}{2} I_x \omega^2$$

***10.14** The moment of inertia of a thin rod about an axis through one end is $I = \tfrac{1}{3}ML^2$. The total rotational kinetic energy is given as

$$K_R = \tfrac{1}{2} I_h \omega_h^2 + \tfrac{1}{2} I_m \omega_m^2$$

with $\quad I_h = \dfrac{m_h L_h^2}{3} = \dfrac{60.0 \text{ kg}(2.70 \text{ m})^2}{3} = 146 \text{ kg} \cdot \text{m}^2$

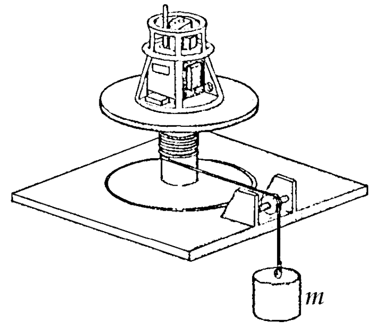
and $\quad I_m = \dfrac{m_m L_m^2}{3} = \dfrac{100 \text{ kg}(4.50 \text{ m})^2}{3} = 675 \text{ kg} \cdot \text{m}^2$

In addition, $\quad \omega_h = \dfrac{2\pi \text{ rad}}{12 \text{ h}}\left(\dfrac{1 \text{ h}}{3600 \text{ s}}\right) = 1.45 \times 10^{-4} \text{ rad/s}$

while $\quad \omega_m = \dfrac{2\pi \text{ rad}}{1 \text{ h}}\left(\dfrac{1 \text{ h}}{3600 \text{ s}}\right) = 1.75 \times 10^{-3} \text{ rad/s}$

Therefore, $\quad K_R = \tfrac{1}{2}(146)\left(1.45 \times 10^{-4}\right)^2 + \tfrac{1}{2}(675)\left(1.75 \times 10^{-3}\right)^2 = \boxed{1.04 \times 10^{-3} \text{ J}}$

***10.15** From conservation of energy for the object-turntable-cylinder-Earth system,

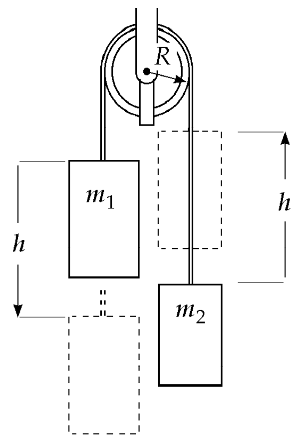


$$\frac{1}{2}I\left(\frac{v}{r}\right)^2 + \frac{1}{2}mv^2 = mgh$$

$$I\frac{v^2}{r^2} = 2mgh - mv^2$$

$$I = \boxed{mr^2\left(\frac{2gh}{v^2} - 1\right)}$$

10.16 Take the two objects, pulley, and Earth as the system. If we neglect friction in the system, then mechanical energy is conserved and we can state that the increase in kinetic energy of the system equals the decrease in potential energy. Since $K_i = 0$ (the system is initially at rest), we have



$$\Delta K = K_f - K_i = \frac{1}{2}m_1v^2 + \frac{1}{2}m_2v^2 + \frac{1}{2}I\omega^2$$

where m_1 and m_2 have a common speed.

But $v = R\omega$

so that $\Delta K = \frac{1}{2}\left(m_1 + m_2 + \frac{I}{R^2}\right)v^2$

From Figure P10.16, we see that a loss of gravitational energy is associated with the motion of m_1 and a gain with the motion of m_2.

Applying the law of conservation of energy $\Delta K + \Delta U = 0$

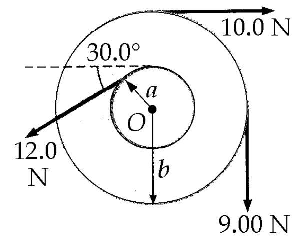
gives $\frac{1}{2}\left(m_1 + m_2 + \frac{I}{R^2}\right)v^2 + m_2gh - m_1gh = 0$

$$\boxed{v = \sqrt{\frac{2(m_1 - m_2)gh}{\left(m_1 + m_2 + \frac{I}{R^2}\right)}}}$$

Since $v = R\omega$, the angular speed of the pulley at this instant is given by

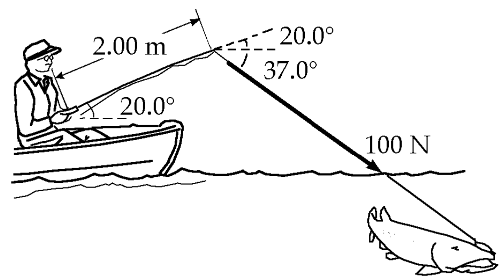
$$\boxed{\omega = \frac{v}{R} = \sqrt{\frac{2(m_1 - m_2)gh}{\left(m_1R^2 + m_2R^2 + I\right)}}}$$

10.17 $\Sigma\tau = 0.100 \text{ m}(12.0 \text{ N}) - 0.250 \text{ m}(9.00 \text{ N}) - 0.250 \text{ m}(10.0 \text{ N}) = \boxed{-3.55 \text{ N}\cdot\text{m}}$



The thirty-degree angle is unnecessary information.

10.18 Resolve the 100 N force into components perpendicular to and parallel to the rod, as



$$F_{par} = (100 \text{ N})\cos 57.0° = 54.5 \text{ N}$$

and $F_{perp} = (100 \text{ N})\sin 57.0° = 83.9 \text{ N}$

The torque of F_{par} is zero since its line of action passes through the pivot point.

The torque of F_{perp} is $\tau = 83.9 \text{ N}(2.00 \text{ m}) = \boxed{168 \text{ N}\cdot\text{m}}$ (clockwise)

10.19 $$\mathbf{M}\times\mathbf{N} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 6 & 2 & -1 \\ 2 & -1 & -3 \end{vmatrix} = \boxed{-7.00\mathbf{i} + 16.0\mathbf{j} - 10.0\mathbf{k}}$$

***10.20** $\mathbf{A}\cdot\mathbf{B} = -3.00(6.00) + 7.00(-10.0) + (-4.00)(9.00) = -124$

$$AB = \sqrt{(-3.00)^2 + (7.00)^2 + (-4.00)^2}\cdot\sqrt{(6.00)^2 + (-10.0)^2 + (9.00)^2} = 127$$

(a) $\cos^{-1}\left(\frac{\mathbf{A}\cdot\mathbf{B}}{AB}\right) = \cos^{-1}(-0.979) = \boxed{168°}$

(b) $$\mathbf{A}\times\mathbf{B} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ -3.00 & 7.00 & -4.00 \\ 6.00 & -10.0 & 9.00 \end{vmatrix} = 23.0\,\mathbf{i} + 3.00\,\mathbf{j} - 12.0\,\mathbf{k}$$

$$|\mathbf{A}\times\mathbf{B}| = \sqrt{(23.0)^2 + (3.00)^2 + (-12.0)^2} = 26.1$$

$$\sin\left(\frac{|\mathbf{A}\times\mathbf{B}|}{AB}\right) = \sin^{-1}(0.206) = \boxed{11.9°} \quad \text{or} \quad 168°$$

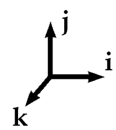
(c) Only $\boxed{\text{the first method}}$ gives the angle between the vectors unambiguously.

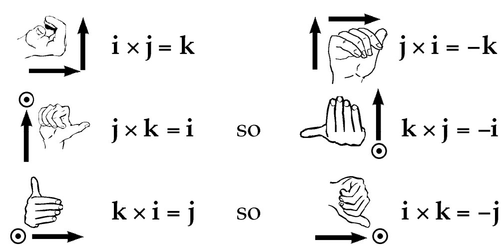
10.21 (a) $\tau = \mathbf{r} \times \mathbf{F} = (4.00\mathbf{i} + 5.00\mathbf{j}) \times (2.00\mathbf{i} + 3.00\mathbf{j})$

$$\tau = |12.00\,\mathbf{k} - 10.0\,\mathbf{k}| = |2.00\,\mathbf{k}| = \boxed{2.00\ \text{N}\cdot\text{m}}$$

(b) The torque vector is in the direction of the unit vector **k**, or in the $\boxed{+z \text{ direction}}$

***10.22** $|\mathbf{i}\times\mathbf{i}| = 1\cdot 1\cdot \sin 0° = 0$





j × **j** and **k** × **k** are zero similarly since the vectors being multiplied are parallel.

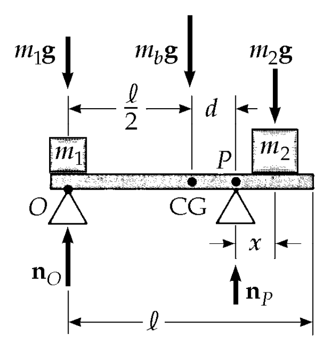
$|\mathbf{i}\times\mathbf{j}| = 1\cdot 1\cdot \sin 90° = 1$

***10.23** Take torques about P.

$$\Sigma\tau_p = -n_0\left[\frac{\ell}{2} + d\right] + m_1 g\left[\frac{\ell}{2} + d\right] + m_b g d - m_2 g x = 0$$

We want to find x for which $n_0 = 0$.

$$x = \frac{(m_1 g + m_b g)d + m_1 g\ell/2}{m_2 g} = \boxed{\frac{(m_1 + m_b)d + m_1\ell/2}{m_2}}$$



10.24 Torque about the front wheel is zero.

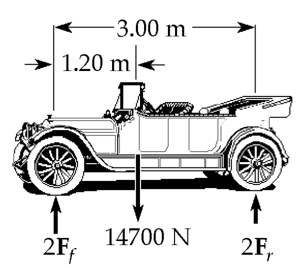
$$0 = (1.20\ \text{m})(mg) - (3.00\ \text{m})(2F_r)$$

Thus, the force at each rear wheel is

$$F_r = 0.200mg = \boxed{2.94\ \text{kN}}$$

The force at each front wheel is then

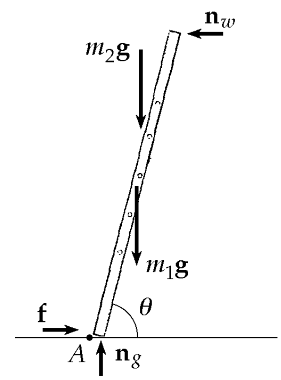
$$F_f = \frac{mg - 2F_r}{2} = \boxed{4.41\ \text{kN}}$$



***10.25** (a) $\Sigma F_x = f - n_w = 0$ (1)

$\Sigma F_y = n_g - m_1 g - m_2 g = 0$ (2)

$$\Sigma \tau_A = -m_1 g\left(\frac{L}{2}\right)\cos\theta - m_2 g x\cos\theta + n_w L\sin\theta = 0$$



From the torque equation,

$$n_w = \left[\frac{1}{2}m_1 g + \left(\frac{x}{L}\right)m_2 g\right]\cot\theta$$

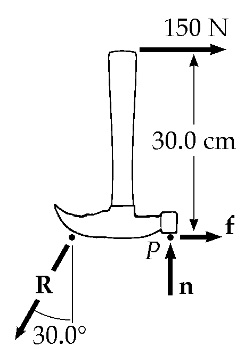
Then, from equation (1): $\boxed{f = n_w = \left[\frac{1}{2}m_1 g + \left(\frac{x}{L}\right)m_2 g\right]\cot\theta}$

and from equation (2): $\boxed{n_g = (m_1 + m_2)g}$

(b) If the ladder is on the verge of slipping when $x = d$,

then $$\mu = \frac{f|_{x=d}}{n_g} = \boxed{\frac{\left[\frac{1}{2}m_1 + \left(\frac{d}{L}\right)m_2\right]\cot\theta}{m_1 + m_2}}$$

***10.26** (a) Taking moments about P,



$(R \sin 30.0°)0 + (R \cos 30.0°)(5.00 \text{ cm}) - (150 \text{ N})(30.0 \text{ cm}) = 0$

$R = 1039.2 \text{ N} = 1.04 \text{ kN}$

The force exerted by the hammer on the nail is equal in magnitude and opposite in direction:

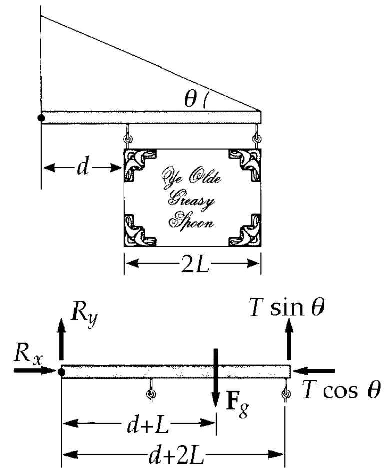
$\boxed{\text{1.04 kN at 60° upward and to the right.}}$

(b) $f = R \sin 30.0° - 150 \text{ N} = 370 \text{ N}$

$n = R \cos 30.0° = 900 \text{ N}$

$\boxed{\mathbf{F}_{\text{surface}} = (370 \text{ N})\mathbf{i} + (900 \text{ N})\mathbf{j}}$

***10.27** Using $\Sigma F_x = \Sigma F_y = \Sigma\tau = 0$, choosing the origin at the left end of the beam, we have (neglecting the weight of the beam)



$$\Sigma F_x = R_x - T\cos\theta = 0,$$

$$\Sigma F_y = R_y + T\sin\theta - F_g = 0,$$

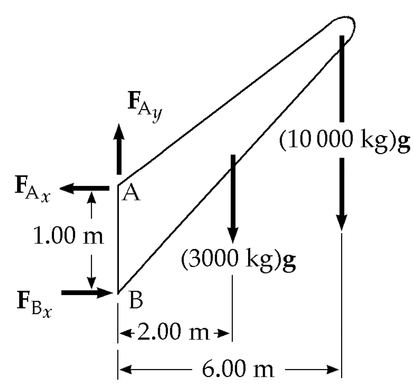
and $\Sigma\tau = -F_g(L+d) + T\sin\theta(2L+d) = 0$

Solving these equations, we find:

(a) $T = \boxed{\dfrac{F_g(L+d)}{\sin\theta(2L+d)}}$

(b) $R_x = \boxed{\dfrac{F_g(L+d)\cot\theta}{2L+d}}$ $R_y = \boxed{\dfrac{F_g L}{2L+d}}$

10.28 We interpret the problem to mean that the support at point B is frictionless. Then the support exerts a force in the x direction and



$$\boxed{F_{By} = 0}$$

$$\Sigma F_x = F_{Bx} - F_{Ax} = 0$$

$$F_{Ay} - (3000 + 10\,000)g = 0$$

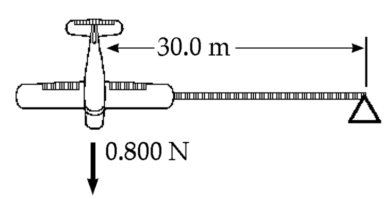
and $\Sigma\tau = -(3000g)(2.00) - (10\,000g)(6.00) + F_{Bx}(1.00) = 0$

These equations combine to give

$$F_{Ax} = F_{Bx} = \boxed{6.47 \times 10^5 \text{ N}}$$

$$F_{Ay} = \boxed{1.27 \times 10^5 \text{ N}}$$

10.29 $m = 0.750$ kg, $F = 0.800$ N



(a) $\tau = rF = 30.0 \text{ m}(0.800 \text{ N}) = \boxed{24.0 \text{ N}\cdot\text{m}}$

(b) $\alpha = \dfrac{\tau}{I} = \dfrac{rF}{mr^2} = \dfrac{24.0}{0.750(30.0)^2} = \boxed{0.0356 \text{ rad/s}^2}$

(c) $a_t = \alpha r = 0.0356(30.0) = \boxed{1.07 \text{ m/s}^2}$

10.30 $\omega_f = \omega_i + \alpha t$: $10.0 \text{ rad/s} = 0 + \alpha(6.00 \text{ s})$

$$\alpha = \frac{10.00}{6.00} \text{ rad/s}^2 = 1.67 \text{ rad/s}^2$$

(a) $\Sigma\tau = 36.0 \text{ N}\cdot\text{m} = I\alpha$: $I = \frac{\Sigma\tau}{\alpha} = \frac{36.0 \text{ N}\cdot\text{m}}{1.67 \text{ rad/s}^2} = \boxed{21.6 \text{ kg}\cdot\text{m}^2}$

(b) $\omega_f = \omega_i + \alpha t$: $0 = 10.0 + \alpha(60.0)$

$$\alpha = -0.167 \text{ rad/s}^2$$

$$|\tau| = |I\alpha| = (21.6 \text{ kg}\cdot\text{m}^2)(0.167 \text{ rad/s}^2) = \boxed{3.60 \text{ N}\cdot\text{m}}$$

(c) Number of revolutions $\theta_f = \theta_i + \omega_i t + \frac{1}{2}\alpha t^2$

During first 6.00 s $\theta_f = \frac{1}{2}(1.67)(6.00)^2 = 30.1 \text{ rad}$

During next 60.0 s $\theta_f = 10.0(60.0) - \frac{1}{2}(0.167)(60.0)^2 = 299 \text{ rad}$

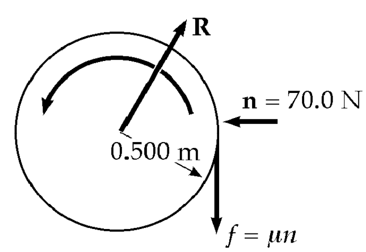
$$\theta_{\text{total}} = 329 \text{ rad}\left(\frac{1 \text{ rev}}{2\pi \text{ rad}}\right) = \boxed{52.4 \text{ rev}}$$

***10.31** $\Sigma\tau = I\alpha = \frac{1}{2}MR^2\alpha$

$$-135 \text{ N}(0.230 \text{ m}) + T(0.230 \text{ m}) = \frac{1}{2}(80 \text{ kg})\left(\frac{1.25}{2} \text{ m}\right)^2(-1.67 \text{ rad/s}^2)$$

$T = \boxed{21.5 \text{ N}}$

***10.32** $I = \frac{1}{2}mR^2 = \frac{1}{2}(100 \text{ kg})(0.500 \text{ m})^2 = 12.5 \text{ kg}\cdot\text{m}^2$



$\omega_i = 50.0 \text{ rev/min} = 5.24 \text{ rad/s}$

$$\alpha = \frac{\omega_f - \omega_i}{t} = \frac{0 - 5.24 \text{rad/s}}{6.00 \text{ s}} = -0.873 \text{ rad/s}^2$$

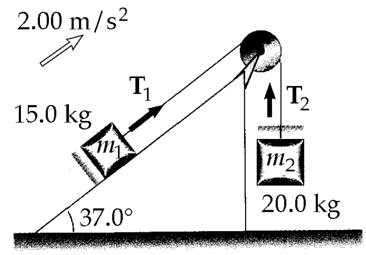
$$\tau = I\alpha = 12.5 \text{ kg}\cdot\text{m}^2(-0.873 \text{ rad/s}^2) = -10.9 \text{ N}\cdot\text{m}$$

The magnitude of the torque is given by $fR = 10.9 \text{ N}\cdot\text{m}$, where f is the force of friction.

Therefore, $f = \frac{10.9 \text{ N}\cdot\text{m}}{0.500 \text{ m}}$ and $f = \mu_k n$

yields $\mu_k = \frac{f}{n} = \frac{21.8 \text{ N}}{70.0 \text{ N}} = \boxed{0.312}$

10.33 (a) $m_2 g - T_2 = m_2 a$



$$T_2 = m_2(g - a) = 20.0\text{ kg}\left(9.80\text{ m/s}^2 - 2.00\text{ m/s}^2\right) = \boxed{156\text{ N}}$$

$$T_1 - m_1 g \sin 37.0° = m_1 a$$

$$T_1 = (15.0\text{ kg})(9.80\sin 37.0° + 2.00)\text{ m/s}^2 = \boxed{118\text{ N}}$$

(b) $(T_2 - T_1)R = I\alpha = I\left(\dfrac{a}{R}\right)$

$$I = \frac{(T_2 - T_1)R^2}{a} = \frac{(156\text{ N} - 118\text{ N})(0.250\text{ m})^2}{2.00\text{ m/s}^2} = \boxed{1.17\text{ kg}\cdot\text{m}^2}$$

***10.34** (a) $I = \frac{1}{2}M\left(R_1^2 + R_2^2\right) = \frac{1}{2}(0.35\text{ kg})\left[(0.02\text{ m})^2 + (0.03\text{ m})^2\right] = 2.28\times 10^{-4}\text{ kg}\cdot\text{m}^2$

$$\left(K_1 + K_2 + K_{rot} + U_{g2}\right)_i - f_k\Delta x = \left(K_1 + K_2 + K_{rot}\right)_f$$

$$\tfrac{1}{2}(0.850\text{ kg})(0.82\text{ m/s})^2 + \tfrac{1}{2}(0.42\text{ kg})(0.82\text{ m/s})^2 + \tfrac{1}{2}\left(2.28\times 10^{-4}\text{ kg}\cdot\text{m}^2\right)\left(\frac{0.82\text{ m/s}}{0.03\text{ m}}\right)^2$$

$$+0.42\text{ kg}\left(9.8\text{ m/s}^2\right)(0.7\text{ m}) - 0.25(0.85\text{ kg})\left(9.8\text{ m/s}^2\right)(0.7\text{ m})$$

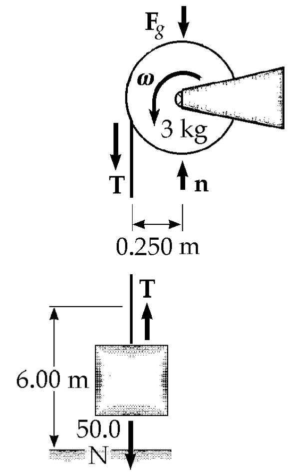
$$= \tfrac{1}{2}(0.85\text{ kg})v_f^2 + \tfrac{1}{2}(0.42\text{ kg})v_f^2 + \tfrac{1}{2}\left(2.28\times 10^{-4}\text{ kg}\cdot\text{m}^2\right)\left(\frac{v_f}{0.03\text{ m}}\right)^2$$

$$0.512\text{ J} + 2.88\text{ J} - 1.46\text{ J} = (0.761\text{ kg})v_f^2$$

$$v_f = \sqrt{\frac{1.94\text{ J}}{0.761\text{ kg}}} = \boxed{1.59\text{ m/s}}$$

(b) $\omega = \dfrac{v}{r} = \dfrac{1.59\text{ m/s}}{0.03\text{ m}} = \boxed{53.1\text{ rad/s}}$

***10.35** (a) For the counterweight,



$\Sigma F_y = ma_y$ becomes $$50.0 - T = \left(\frac{50.0}{9.80}\right)a$$

For the reel $\Sigma\tau = I\alpha$ reads $$TR = I\alpha = I\frac{a}{R}$$

where $$I = \frac{1}{2}MR^2 = 0.0938\ \text{kg}\cdot\text{m}^2$$

We substitute to eliminate the acceleration:

$$50.0 - T = 5.10\left(\frac{TR^2}{I}\right)$$

$$T = \boxed{11.4\ \text{N}} \quad \text{and} \quad a = \frac{50.0 - 11.4}{5.10} = \boxed{7.57\ \text{m/s}^2}$$

$v_f^2 = v_i^2 + 2a(x_f - x_i)$: $$v_f = \sqrt{2(7.57)6.00} = \boxed{9.53\ \text{m/s}}$$

(b) Use conservation of energy for the system of the object, the reel, and the Earth:

$(K+U)_i = (K+U)_f$: $$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

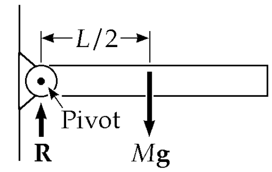
$$2mgh = mv^2 + I\left(\frac{v^2}{R^2}\right) = v^2\left(m + \frac{I}{R^2}\right)$$

$$v = \sqrt{\frac{2mgh}{m + \frac{I}{R^2}}} = \sqrt{\frac{2(50.0\ \text{N})(6.00\ \text{m})}{5.10\ \text{kg} + \frac{0.0938}{(0.250)^2}}} = \boxed{9.53\ \text{m/s}}$$

***10.36** $\tau\cdot\theta = \frac{1}{2}I\omega^2$: $$25.0\ \text{N}\cdot\text{m}(15.0\cdot 2\pi) = \frac{1}{2}\left(0.130\ \text{kg}\cdot\text{m}^2\right)\omega^2$$

$$\omega = \boxed{190\ \text{rad/s}} = 30.3\ \text{rev/s}$$

10.37 For the purpose of computing the torque on the rod, we recall that the whole weight Mg can be modeled as acting at the center of mass of the rod. Because the rod is uniform, its center of mass is at its geometric center. The magnitude of the torque due to this force about an axis through the pivot is



$$\tau = \frac{MgL}{2}$$

The support force at the hinge has zero torque about an axis through the pivot, because this force passes through the axis (hence $r = 0$). Since $\tau = I\alpha$, where $I = \frac{1}{3}ML^2$ for this axis of rotation (see Table 10.2), we get

$$I\alpha = Mg\frac{L}{2}: \qquad \alpha = \frac{Mg(L/2)}{\frac{1}{3}ML^2} = \boxed{\frac{3g}{2L}}$$

The angular acceleration is common to *all* points on the rod.

To find the linear acceleration of the right end of the rod, we use the relation $a_t = R\alpha$ with $R = L$:

This gives $\qquad a_t = L\alpha = \boxed{\frac{3}{2}g}$

This result is rather interesting, since $a_t > g$. That is, the end of the rod has an acceleration *greater* than the acceleration due to gravity. Therefore, if a coin were placed at the end of the rod, the end of the rod would fall faster than the coin when released.

Other points on the rod have a linear acceleration less than $\frac{3}{2}g$. For example, the middle of the rod has an acceleration $\frac{3}{4}g$.

10.38 Whether we think of the Earth's surface as curved or flat, we interpret the problem to mean that the plane's line of flight extended is precisely tangent to the mountain at its peak, and nearly parallel to the wheat field. Let the positive x direction be eastward, positive y be northward, and positive z be vertically upward.

(a) $\mathbf{r} = (4.30\text{ km})\mathbf{k} = (4.30 \times 10^3\text{ m})\mathbf{k}$

$\mathbf{p} = m\mathbf{v} = 12\,000\text{ kg}(-175\mathbf{i}\text{ m/s}) = -2.10 \times 10^6\mathbf{i}\text{ kg}\cdot\text{m/s}$

$\mathbf{L} = \mathbf{r} \times \mathbf{p} = (4.30 \times 10^3\mathbf{k}\text{ m}) \times (-2.10 \times 10^6\mathbf{i}\text{ kg}\cdot\text{m/s}) = \boxed{\left(-9.03 \times 10^9\text{ kg}\cdot\text{m}^2/\text{s}\right)\mathbf{j}}$

(b) $\boxed{\text{No}}$. $L = |\mathbf{r}||\mathbf{p}|\sin\theta = mv(r\sin\theta)$, and $r\sin\theta$ is the altitude of the plane. Therefore, $L = constant$ as the plane moves in level flight with constant velocity.

(c) $\boxed{\text{Zero}}$. The position vector from Pike's Peak to the plane is anti-parallel to the velocity of the plane. That is, it is directed along the same line and opposite in direction.

Thus, $\qquad L = mvr\sin 180° = 0$

10.39 $\mathbf{r} = (6.00\mathbf{i} + 5.00t\,\mathbf{j})$ m $\quad \mathbf{v} = \frac{d\mathbf{r}}{dt} = 5.00\mathbf{j}$ m/s

so $\mathbf{p} = m\mathbf{v} = 2.00\text{ kg}(5.00\mathbf{j}\text{ m/s}) = 10.0\mathbf{j}\text{ kg}\cdot\text{m/s}$

and $$\mathbf{L} = \mathbf{r}\times\mathbf{p} = \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 6.00 & 5.00t & 0 \\ 0 & 10.0 & 0 \end{vmatrix} = \boxed{\left(60.0\text{ kg}\cdot\text{m}^2/\text{s}\right)\mathbf{k}}$$

***10.40** The total angular momentum about the center point is given by $L = I_h\omega_h + I_m\omega_m$

with $$I_h = \frac{m_h L_h^2}{3} = \frac{60.0\text{ kg}(2.70\text{ m})^2}{3} = 146\text{ kg}\cdot\text{m}^2$$

and $$I_m = \frac{m_m L_m^2}{3} = \frac{100\text{ kg}(4.50\text{ m})^2}{3} = 675\text{ kg}\cdot\text{m}^2$$

In addition, $$\omega_h = \frac{2\pi\text{ rad}}{12\text{ h}}\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 1.45\times10^{-4}\text{ rad/s}$$

while $$\omega_m = \frac{2\pi\text{ rad}}{1\text{ h}}\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 1.75\times10^{-3}\text{ rad/s}$$

Thus, $$L = 146\text{ kg}\cdot\text{m}^2\left(1.45\times10^{-4}\frac{\text{rad}}{\text{s}}\right) + 675\text{ kg}\cdot\text{m}^2\left(1.75\times10^{-3}\frac{\text{rad}}{\text{s}}\right)$$

or $$\boxed{L = 1.20\text{ kg}\cdot\text{m}^2/\text{s}}$$

***10.41** (a) $I = \frac{1}{12}m_1L^2 + m_2(0.500)^2 = \frac{1}{12}(0.100)(1.00)^2 + 0.400(0.500)^2 = 0.1083\text{ kg}\cdot\text{m}^2$

$L = I\omega = 0.1083(4.00) = \boxed{0.433\text{ kg}\cdot\text{m}^2/\text{s}}$

(b) $I = \frac{1}{3}m_1L^2 + m_2R^2 = \frac{1}{3}(0.100)(1.00)^2 + 0.400(1.00)^2 = 0.433$

$L = I\omega = 0.433(4.00) = \boxed{1.73\text{ kg}\cdot\text{m}^2/\text{s}}$

***10.42** (a) The initial torque is $|\tau| = |\mathbf{r}\times\mathbf{F}| = 8.00\times10^{-2}\text{ m}(4.00\text{ kg})(9.80\text{ m/s}^2) = \boxed{3.14\text{ N}\cdot\text{m}}$

(b) $|\mathbf{L}| = |\mathbf{r}\times m\mathbf{v}| + I\omega \qquad |\mathbf{L}| = Rmv + \frac{1}{2}MR^2\left(\frac{v}{R}\right) = R\left(m + \frac{M}{2}\right)v = \boxed{(0.400\text{ kg}\cdot\text{m})\,v}$

(c) $\tau = \frac{dL}{dt} = (0.400\text{ kg}\cdot\text{m})a \qquad a = \frac{3.14\text{ N}\cdot\text{m}}{0.400\text{ kg}\cdot\text{m}} = \boxed{7.85\text{ m/s}^2}$

***10.43** (a) From conservation of angular momentum for the system of two cylinders:

$$(I_1 + I_2)\omega_f = I_1\omega_i \qquad \text{or} \qquad \boxed{\omega_f = \frac{I_1}{I_1 + I_2}\omega_i}$$

(b) $$K_f = \tfrac{1}{2}(I_1 + I_2)\omega_f^2 \qquad \text{and} \qquad K_i = \tfrac{1}{2}I_1\omega_i^2$$

so $$\frac{K_f}{K_i} = \frac{\frac{1}{2}(I_1 + I_2)}{\frac{1}{2}I_1\omega_i^2}\left(\frac{I_1}{I_1 + I_2}\omega_i\right)^2 = \boxed{\frac{I_1}{I_1 + I_2} \text{ which is less than 1}}$$

10.44 (a) The total angular momentum of the system of the student, the stool, and the weights about the axis of rotation is given by

$$I_{\text{total}} = I_{\text{weights}} + I_{\text{student}} = 2\left(mr^2\right) + 3.00 \text{ kg}\cdot\text{m}^2$$

Before: $r = 1.00$ m.

Thus, $I_i = 2(3.00 \text{ kg})(1.00 \text{ m})^2 + 3.00 \text{ kg}\cdot\text{m}^2 = 9.00 \text{ kg}\cdot\text{m}^2$

After: $r = 0.300$ m

Thus, $I_f = 2(3.00 \text{ kg})(0.300 \text{ m})^2 + 3.00 \text{ kg}\cdot\text{m}^2 = 3.54 \text{ kg}\cdot\text{m}^2$

We now use conservation of angular momentum.

$$I_f\omega_f = I_i\omega_i$$

or $$\omega_f = \left(\frac{I_i}{I_f}\right)\omega_i = \left(\frac{9.00}{3.54}\right)(0.750 \text{ rad/s}) = \boxed{1.91 \text{ rad/s}}$$

(b) $$K_i = \tfrac{1}{2}I_i\omega_i^2 = \tfrac{1}{2}\left(9.00 \text{ kg}\cdot\text{m}^2\right)(0.750 \text{ rad/s})^2 = \boxed{2.53 \text{ J}}$$

$$K_f = \tfrac{1}{2}I_f\omega_f^2 = \tfrac{1}{2}\left(3.54 \text{ kg}\cdot\text{m}^2\right)(1.91 \text{ rad/s})^2 = \boxed{6.44 \text{ J}}$$

***10.45** $I_i\omega_i = I_f\omega_f$: $\left(250 \text{ kg}\cdot\text{m}^2\right)(10.0 \text{ rev/min}) = \left[250 \text{ kg}\cdot\text{m}^2 + 25.0 \text{ kg}(2.00 \text{ m})^2\right]\omega_2$

$$\omega_2 = \boxed{7.14 \text{ rev/min}}$$

10.46 When they touch, the center of mass is distant from the center of the larger puck by

$$y_{CM} = \frac{0 + 80.0\text{ g}(4.00\text{ cm} + 6.00\text{ cm})}{120\text{ g} + 80.0\text{ g}} = 4.00\text{ cm}$$

(a) $L = r_1 m_1 v_1 + r_2 m_2 v_2 = 0 + \left(6.00 \times 10^{-2}\text{ m}\right)\left(80.0 \times 10^{-3}\text{ kg}\right)(1.50\text{ m/s}) = \boxed{7.20 \times 10^{-3}\text{ kg}\cdot\text{m}^2/\text{s}}$

(b) The moment of inertia about the CM is

$$I = \left(\tfrac{1}{2} m_1 r_1^2 + m_1 d_1^2\right) + \left(\tfrac{1}{2} m_2 r_2^2 + m_2 d_2^2\right)$$

$$I = \tfrac{1}{2}(0.120\text{ kg})\left(6.00 \times 10^{-2}\text{ m}\right)^2 + (0.120\text{ kg})\left(4.00 \times 10^{-2}\right)^2$$

$$+\tfrac{1}{2}\left(80.0 \times 10^{-3}\text{ kg}\right)\left(4.00 \times 10^{-2}\text{ m}\right)^2 + \left(80.0 \times 10^{-3}\text{ kg}\right)\left(6.00 \times 10^{-2}\text{ m}\right)^2$$

$$I = 7.60 \times 10^{-4}\text{ kg}\cdot\text{m}^2$$

Angular momentum of the two-puck system is conserved: $L = I\omega$

$$\omega = \frac{L}{I} = \frac{7.20 \times 10^{-3}\text{ kg}\cdot\text{m}^2/\text{s}}{7.60 \times 10^{-4}\text{ kg}\cdot\text{m}^2} = \boxed{9.47\text{ rad/s}}$$

***10.47** For one of the crew,

$\Sigma F_r = ma_r$: $\quad n = mv^2/r = m\omega_i^2 r$

We require $\quad n = mg$, so $\omega_i = \sqrt{g/r}$

Now, $\quad I_i\omega_i = I_f\omega_f$

$$\left[5.00 \times 10^8\text{ kg}\cdot\text{m}^2 + 150 \times 65.0\text{ kg} \times (100\text{ m})^2\right]\sqrt{g/r} = \left[5.00 \times 10^8\text{ kg}\cdot\text{m}^2 + 50 \times 65.0\text{ kg}\ (100\text{ m})^2\right]\omega_f$$

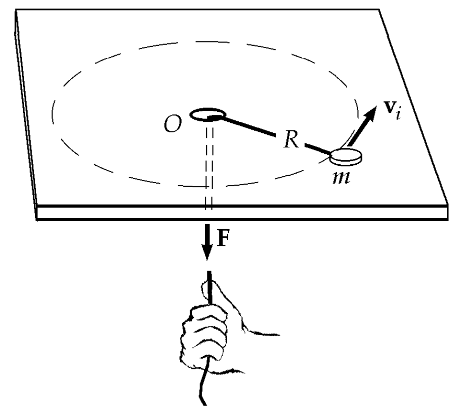
$$\left(\frac{5.98 \times 10^8}{5.32 \times 10^8}\right)\sqrt{g/r} = \omega_f = 1.12\sqrt{g/r}$$

Now, $\quad |a_r| = \omega_f^2 r = 1.26g = \boxed{12.3\text{ m/s}^2}$

10.48 $I_i = mr_i^2 = 0.12\text{ kg}(0.4\text{ m})^2 = 1.92\times10^{-2}\text{ kg}\cdot\text{m}^2$

$I_f = mr_f^2 = 0.12\text{ kg}(0.25\text{ m})^2 = 7.5\times10^{-3}\text{ kg}\cdot\text{m}^2$

$\omega_i = \frac{v_i}{r_i} = \frac{0.8\text{ m/s}}{0.4\text{ m}} = 2\text{ rad/s}$



Now, use conservation of angular momentum for the system of the ball

$$\omega_f = \omega_i\left(\frac{I_i}{I_f}\right) = (2\text{ rad/s})\left(\frac{1.92\times10^{-2}\text{ kg}\cdot\text{m}^2}{7.5\times10^{-3}\text{ kg}\cdot\text{m}^2}\right) = 5.12\text{ rad/s}$$

The work done $= \Delta K = \frac{1}{2}I_f\omega_f^2 - \frac{1}{2}I_i\omega_i^2$

Substituting the appropriate values found earlier, we have the work done: $\boxed{5.99\times10^{-2}\text{ J}}$

10.49 (a) $K_{\text{trans}} = \frac{1}{2}mv^2 = \frac{1}{2}(10.0\text{ kg})(10.0\text{ m/s})^2 = \boxed{500\text{ J}}$

(b) $K_{\text{rot}} = \frac{1}{2}I\omega^2 = \frac{1}{2}\left(\frac{1}{2}mr^2\right)\left(\frac{v^2}{r^2}\right) = \frac{1}{4}(10.0\text{ kg})(10.0\text{ m/s})^2 = \boxed{250\text{ J}}$

(c) $K_{\text{total}} = K_{\text{trans}} + K_{\text{rot}} = \boxed{750\text{ J}}$

***10.50** $K = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 = \frac{1}{2}\left[m + \frac{I}{R^2}\right]v^2$ where $\omega = \frac{v}{R}$ since no slipping.

Also, $U_i = mgh,\ U_f = 0,$ and $v_i = 0$

Therefore, $\frac{1}{2}\left[m + \frac{I}{R^2}\right]v^2 = mgh$

Thus, $v^2 = \frac{2gh}{\left[1 + \left(I/mR^2\right)\right]}$

For a disk, $I = \frac{1}{2}mR^2$

So $v^2 = \frac{2gh}{1 + (1/2)}$ or $\boxed{v_{\text{disk}} = \sqrt{\frac{4gh}{3}}}$

For a ring, $I = mR^2$ so $v^2 = \frac{2gh}{2}$ or $\boxed{v_{\text{ring}} = \sqrt{gh}}$

Since $v_{\text{disk}} > v_{\text{ring}}$, $\boxed{\text{the disk}}$ reaches the bottom first.

10.51 $\bar{v} = \frac{\Delta x}{\Delta t} = \frac{3.00\text{ m}}{1.50\text{ s}} = 2.00\text{ m/s} = \frac{1}{2}\left(0 + v_f\right)$

$v_f = 4.00\text{ m/s}$ and $\omega_f = \frac{v_f}{r} = \frac{4.00\text{ m/s}}{\left(6.38\times10^{-2}\text{ m}\right)/2} = \frac{8.00}{6.38\times10^{-2}}\text{ rad/s}$

We ignore internal friction and suppose the can rolls without slipping.

$$\left(K_{\text{trans}} + K_{rot} + U_g\right)_i + \Delta E_{\text{mech}} = \left(K_{\text{trans}} + K_{rot} + U_g\right)_f$$

$$\left(0 + 0 + mgy_i\right) + 0 = \left(\tfrac{1}{2}mv_f^2 + \tfrac{1}{2}I\omega_f^2 + 0\right)$$

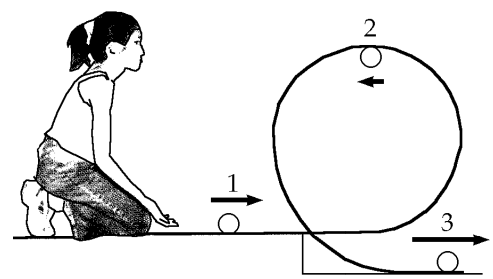
$$0.215\text{ kg}\left(9.80\text{ m/s}^2\right)\left[(3.00\text{ m})\sin 25.0°\right] = \tfrac{1}{2}(0.215\text{ kg})(4.00\text{ m/s})^2 + \tfrac{1}{2}I\left(\frac{8.00}{6.38\times10^{-2}}\text{ rad/s}\right)^2$$

$$2.67\text{ J} = 1.72\text{ J} + \left(7860\text{ s}^{-2}\right)I$$

$$I = \frac{0.951\text{ kg}\cdot\text{m}^2/\text{s}^2}{7860\text{ s}^{-2}} = \boxed{1.21\times10^{-4}\text{ kg}\cdot\text{m}^2}$$

The **[height of the can]** is unnecessary data.

***10.52** (a) Energy conservation for the system of the ball and the Earth between the horizontal section and top of loop:



$$\tfrac{1}{2}mv_2^2 + \tfrac{1}{2}I\omega_2^2 + mgy_2 = \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}I\omega_1^2$$

$$\tfrac{1}{2}mv_2^2 + \tfrac{1}{2}\left(\tfrac{2}{3}mr^2\right)\left(\frac{v_2}{r}\right)^2 + mgy_2 = \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}\left(\tfrac{2}{3}mr^2\right)\left(\frac{v_1}{r}\right)^2$$

$$\tfrac{5}{6}v_2^2 + gy_2 = \tfrac{5}{6}v_1^2$$

$$v_2 = \sqrt{v_1^2 - \tfrac{6}{5}gy_2} = \sqrt{(4.03\text{ m/s})^2 - \tfrac{6}{5}\left(9.80\text{ m/s}^2\right)(0.900\text{ m})} = \boxed{2.38\text{ m/s}}$$

The centripetal acceleration is $\frac{v_2^2}{r} = \frac{(2.38\text{ m/s})^2}{0.450\text{ m}} = 12.6\text{ m/s}^2 > g$

Thus, the ball must be in contact with the track, with the track pushing downward on it.

(b) $\tfrac{1}{2}mv_3^2 + \tfrac{1}{2}\left(\tfrac{2}{3}mr^2\right)\left(\frac{v_3}{r}\right)^2 + mgy_3 = \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}\left(\tfrac{2}{3}mr^2\right)\left(\frac{v_1}{r}\right)^2$

$$v_3 = \sqrt{v_1^2 - \tfrac{6}{5}gy_3} = \sqrt{(4.03\text{ m/s})^2 - \tfrac{6}{5}\left(9.80\text{ m/s}^2\right)(-0.200\text{ m})} = \boxed{4.31\text{ m/s}}$$

(c) $\tfrac{1}{2}mv_2^2 + mgy_2 = \tfrac{1}{2}mv_1^2$

$$v_2 = \sqrt{v_1^2 - 2gy_2} = \sqrt{(4.03\text{ m/s})^2 - 2\left(9.80\text{ m/s}^2\right)(0.900\text{ m})} = \sqrt{-1.40\text{ m}^2/\text{s}^2}$$

This result is imaginary. In the case where the ball does not roll, the ball starts with less energy than in part (a) and **[never makes it to the top]** of the loop.

***10.53** Angular momentum of the system of the spacecraft and the gyroscope is conserved. The gyroscope and spacecraft turn in opposite directions.

$$0 = I_1\omega_1 + I_2\omega_2: \qquad -I_1\omega_1 = I_2\frac{\theta}{t}$$

$$-20\ \text{kg}\cdot\text{m}^2(-100\ \text{rad/s}) = 5\times10^5\ \text{kg}\cdot\text{m}^2\left(\frac{30°}{t}\right)\left(\frac{\pi\ \text{rad}}{180°}\right)$$

$$t = \frac{2.62\times10^5\ \text{s}}{2000} = \boxed{131\ \text{s}}$$

***10.54** $$I = \tfrac{2}{5}MR^2 = \tfrac{2}{5}\left(5.98\times10^{24}\ \text{kg}\right)\left(6.37\times10^6\ \text{m}\right)^2 = 9.71\times10^{37}\ \text{kg}\cdot\text{m}^2$$

$$L = I\omega = 9.71\times10^{37}\ \text{kg}\cdot\text{m}^2\left(\frac{2\pi\ \text{rad}}{86\,400\ \text{s}}\right) = 7.06\times10^{33}\ \text{kg}\cdot\text{m}^2/\text{s}^2$$

$$\tau = L\omega_p = \left(7.06\times10^{33}\ \text{kg}\cdot\text{m}^2/\text{s}\right)\left(\frac{2\pi\ \text{rad}}{2.58\times10^4\ \text{yr}}\right)\left(\frac{1\ \text{yr}}{365.25\ \text{d}}\right)\left(\frac{1\ \text{d}}{86\,400\ \text{s}}\right) = \boxed{5.45\times10^{22}\ \text{N}\cdot\text{m}}$$

10.55 (a) The table turns opposite to the way the woman walks, so its angular momentum cancels that of the woman. From conservation of angular momentum for the system of the woman and the turntable, we have $L_f = L_i = 0$

so, $$L_f = I_{\text{woman}}\omega_{\text{woman}} + I_{\text{table}}\omega_{\text{table}} = 0$$

and $$\omega_{\text{table}} = \left(-\frac{I_{\text{woman}}}{I_{\text{table}}}\right)\omega_{\text{woman}} = \left(-\frac{m_{\text{woman}}r^2}{I_{\text{table}}}\right)\left(\frac{v_{\text{woman}}}{r}\right) = -\frac{m_{\text{woman}}r\,v_{\text{woman}}}{I_{\text{table}}}$$

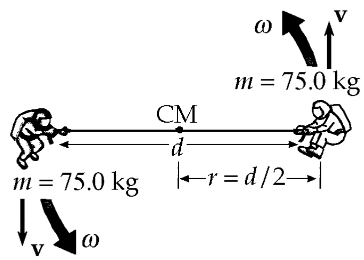
$$\omega_{\text{table}} = -\frac{60.0\ \text{kg}(2.00\ \text{m})(1.50\ \text{m/s})}{500\ \text{kg}\cdot\text{m}^2} = -0.360\ \text{rad/s}$$

or $$\omega_{\text{table}} = \boxed{0.360\ \text{rad/s (counterclockwise)}}$$

(b) $$\text{work done} = \Delta K = K_f - 0 = \tfrac{1}{2}m_{\text{woman}}v_{\text{woman}}^2 + \tfrac{1}{2}I\omega_{\text{table}}^2$$

$$W = \tfrac{1}{2}(60\ \text{kg})(1.50\ \text{m/s})^2 + \tfrac{1}{2}\left(500\ \text{kg}\cdot\text{m}^2\right)(0.360\ \text{rad/s})^2 = \boxed{99.9\ \text{J}}$$

10.56 (a) $L_i = 2\left[Mv\left(\frac{d}{2}\right)\right] = \boxed{Mvd}$



(b) $K = 2\left(\frac{1}{2}Mv^2\right) = \boxed{Mv^2}$

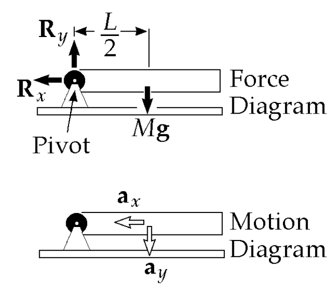
(c) $L_f = L_i = \boxed{Mvd}$

(d) $v_f = \frac{L_f}{2Mr_f} = \frac{Mvd}{2M(d/4)} = \boxed{2v}$

(e) $K_f = 2\left(\frac{1}{2}Mv_f^2\right) = M(2v)^2 = \boxed{4Mv^2}$

(f) $W = K_f - K_i = \boxed{3Mv^2}$

***10.57** (a) Since only conservative forces act within the system of the rod and the Earth,



$\Delta E = 0$ so $K_f + U_f = K_i + U_i$

$$\frac{1}{2}I\omega^2 + 0 = 0 + Mg\left(\frac{L}{2}\right)$$

where $I = \frac{1}{3}ML^2$

Therefore, $\omega = \boxed{\sqrt{3g/L}}$

(b) $\Sigma\tau = I\alpha$, so that in the horizontal orientation,

$$Mg\left(\frac{L}{2}\right) = \frac{ML^2}{3}\alpha$$

$$\alpha = \boxed{\frac{3g}{2L}}$$

(c) $a_x = a_r = -r\omega^2 = -\left(\frac{L}{2}\right)\omega^2 = \boxed{-\frac{3g}{2}}$ $\quad a_y = -a_t = -r\alpha = -\alpha\left(\frac{L}{2}\right) = \boxed{-\frac{3g}{4}}$

(d) Using Newton's second law, we have

$R_x = Ma_x = \boxed{-\frac{3Mg}{2}}$

$R_y - Mg = Ma_y = -\frac{3Mg}{4}$ $\quad R_y = \boxed{\frac{Mg}{4}}$

***10.58** The resistive force on each ball is $R = D\rho A v^2$. Here $v = r\omega$, where r is the radius of each ball's path. The resistive torque on each ball is $\tau = rR$, so the total resistive torque on the three ball system is $\tau_{\text{total}} = 3rR$.

The power required to maintain a constant rotation rate is $\mathcal{P} = \tau_{\text{total}}\omega = 3rR\omega$. This required power may be written as

$$\mathcal{P} = \tau_{\text{total}}\omega = 3r\left[D\rho A(r\omega)^2\right]\omega = \left(3r^3 DA\omega^3\right)\rho$$

With $\omega = \dfrac{2\pi\text{ rad}}{1\text{ rev}}\left(\dfrac{10^3\text{ rev}}{1\text{ min}}\right)\left(\dfrac{1\text{ min}}{60.0\text{ s}}\right) = \dfrac{1000\pi}{30.0}\text{ rad/s}$

$$\mathcal{P} = 3(0.100\text{ m})^3(0.600)\left(4.00\times10^{-4}\text{ m}^2\right)(1000\pi/30.0\text{ s})^3\rho$$

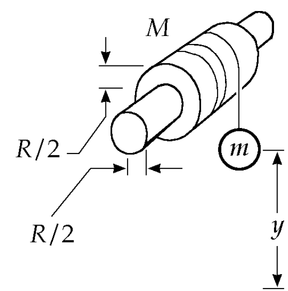
or $\mathcal{P} = \left(0.827\text{ m}^5/\text{s}^3\right)\rho$, where ρ is the density of the resisting medium.

(a) In air, $\rho = 1.20\text{ kg/m}^3$,

and $\mathcal{P} = 0.827\text{ m}^5/\text{s}^3\left(1.20\text{ kg/m}^3\right) = 0.992\text{ N}\cdot\text{m/s} = \boxed{0.992\text{ W}}$

(b) In water, $\rho = 1000\text{ kg/m}^3$ and $\mathcal{P} = \boxed{827\text{ W}}$

***10.59** τ_f will oppose the torque due to the hanging object:



$\Sigma\tau = I\alpha = TR - \tau_f$: $\qquad \tau_f = TR - I\alpha \qquad (1)$

Now find T, I and α in given or known terms and substitute into equation (1).

$\Sigma F_y = T - mg = -ma$: $\qquad T = m(g - a) \qquad (2)$

also $\Delta y = v_i t + \dfrac{at^2}{2}$ $\qquad a = \dfrac{2y}{t^2} \qquad (3)$

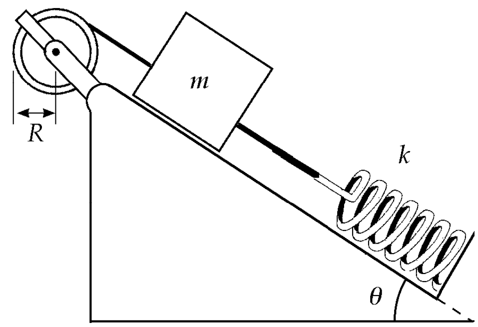
and $\qquad \alpha = \dfrac{a}{R} = \dfrac{2y}{Rt^2}$: $\qquad (4)$

$$I = \tfrac{1}{2}M\left[R^2 + \left(\frac{R}{2}\right)^2\right] = \tfrac{5}{8}MR^2 \qquad (5)$$

Substituting (2), (3), (4), and (5) into (1),

we find $\qquad \tau_f = m\left(g - \dfrac{2y}{t^2}\right)R - \dfrac{5}{8}\dfrac{MR^2(2y)}{Rt^2} = \boxed{R\left[m\left(g - \dfrac{2y}{t^2}\right) - \dfrac{5}{4}\dfrac{My}{t^2}\right]}$

10.60 (a) $W = \Delta K + \Delta U \qquad W = K_f - K_i + U_f - U_i$



$$0 = \tfrac{1}{2}mv^2 + \tfrac{1}{2}I\omega^2 - mgd\sin\theta - \tfrac{1}{2}kd^2$$

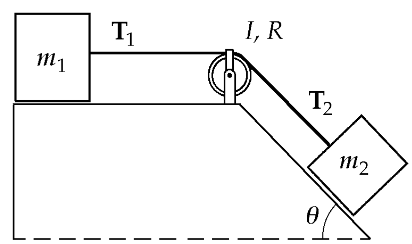
$$\tfrac{1}{2}\omega^2\left(I + mR^2\right) = mgd\sin\theta + \tfrac{1}{2}kd^2$$

$$\boxed{\omega = \sqrt{\frac{2mgd\sin\theta + kd^2}{I + mR^2}}}$$

(b) $$\omega = \sqrt{\frac{2(0.500\text{ kg})(9.80\text{ m/s}^2)(0.200\text{ m})(\sin 37.0°) + 50.0\text{ N/m}(0.200\text{ m})^2}{1.00\text{ kg}\cdot\text{m}^2 + 0.500\text{ kg}(0.300\text{ m})^2}}$$

$$\omega = \sqrt{\frac{1.18 + 2.00}{1.05}} = \sqrt{3.04} = \boxed{1.74\text{ rad/s}}$$

10.61 For m_1, $\Sigma F_y = ma_y$: $+n_1 - m_1 g = 0$

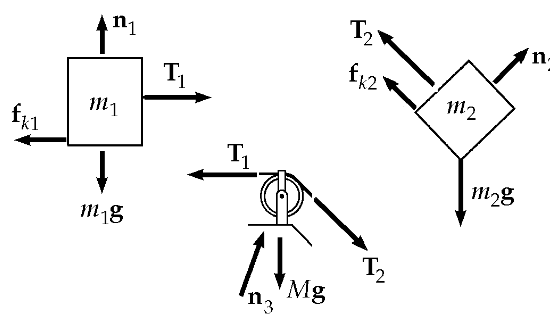


$$n_1 = m_1 g = 19.6\text{ N}$$

$$f_{k1} = \mu_k n_1 = 7.06\text{ N}$$

$$\Sigma F_x = ma_x: \quad -7.06\text{ N} + T_1 = (2.00\text{ kg})a \qquad (1)$$

For the pulley,



$$\Sigma\tau = I\alpha: \quad -T_1R + T_2R = \tfrac{1}{2}MR^2\left(\frac{a}{R}\right)$$

$$-T_1 + T_2 = \tfrac{1}{2}(10.0\text{ kg})a$$

$$-T_1 + T_2 = (5.00\text{ kg})a \qquad (2)$$

For m_2, $\quad +n_2 - m_2 g\cos\theta = 0$

$$n_2 = 6.00\text{ kg}(9.80\text{ m/s}^2)(\cos 30.0°) = 50.9\text{ N}$$

$f_{k2} = \mu_k n_2 = 18.3\text{ N}$: $\quad -18.3\text{ N} - T_2 + m_2 g\sin\theta = m_2 a$

$$-18.3\text{ N} - T_2 + 29.4\text{ N} = (6.00\text{ kg})a \qquad (3)$$

(a) Add equations (1), (2), and (3):

$$-7.06\text{ N} - 18.3\text{ N} + 29.4\text{ N} = (13.0\text{ kg})a$$

$$a = \frac{4.01\text{ N}}{13.0\text{ kg}} = \boxed{0.309\text{ m/s}^2}$$

(b) $$T_1 = 2.00\text{ kg}(0.309\text{ m/s}^2) + 7.06\text{ N} = \boxed{7.67\text{ N}}$$

$$T_2 = 7.67\text{ N} + 5.00\text{ kg}(0.309\text{ m/s}^2) = \boxed{9.22\text{ N}}$$

***10.62** (a) As the bicycle frame moves forward at speed v, the center of each wheel moves forward at the same speed and the wheels turn at angular speed $\omega = v/R$. The total kinetic energy of the bicycle is

$$K = K_{\text{trans}} + K_{rot}$$

or $$K = \tfrac{1}{2}\left(m_{\text{frame}} + 2m_{\text{wheel}}\right)v^2 + 2\left(\tfrac{1}{2}I_{\text{wheel}}\omega^2\right) = \tfrac{1}{2}\left(m_{\text{frame}} + 2m_{\text{wheel}}\right)v^2 + \left(\tfrac{1}{2}m_{\text{wheel}}R^2\right)\left(\frac{v^2}{R^2}\right)$$

This yields $$K = \tfrac{1}{2}\left(m_{\text{frame}} + 3m_{\text{wheel}}\right)v^2 = \tfrac{1}{2}\left[8.44\text{ kg} + 3(0.820\text{ kg})\right](3.35\text{ m/s})^2 = \boxed{61.2\text{ J}}$$

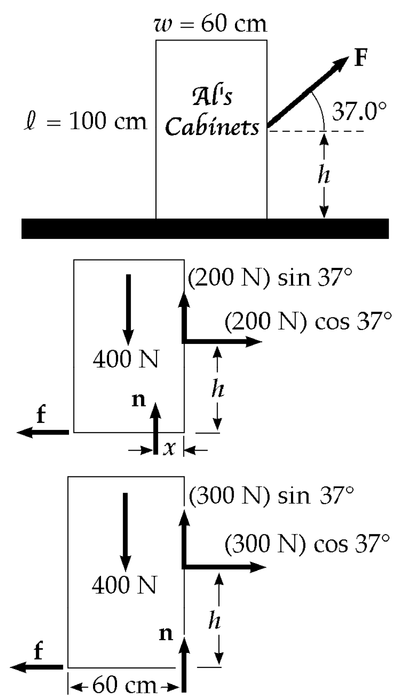
(b) As the block moves forward with speed v, the top of each trunk moves forward at the same speed and the center of each trunk moves forward at speed $v/2$. The angular speed of each roller is $\omega = v/2R$. As in part (a), we have one object undergoing pure translation and two identical objects rolling without slipping. The total kinetic energy of the system of the stone and the trees is

$$K = K_{\text{trans}} + K_{rot}$$

or $$K = \tfrac{1}{2}m_{\text{stone}}v^2 + 2\tfrac{1}{2}m_{\text{tree}}\left(\frac{v}{2}\right)^2 + 2\left(\tfrac{1}{2}I_{\text{tree}}\omega^2\right) = \tfrac{1}{2}\left(m_{\text{stone}} + \tfrac{1}{2}m_{\text{tree}}\right)v^2 + \left(\tfrac{1}{2}m_{\text{tree}}R^2\right)\left(\frac{v^2}{4R^2}\right)$$

This gives $$K = \tfrac{1}{2}\left(m_{\text{stone}} + \tfrac{3}{4}m_{\text{tree}}\right)v^2 = \tfrac{1}{2}\left[844\text{ kg} + 0.75(82.0\text{ kg})\right](0.335\text{ m/s})^2 = \boxed{50.8\text{ J}}$$

***10.63** (a) Locate the origin at the bottom left corner of the cabinet and let x = distance between the *resultant normal force* and the *front of the cabinet.* Then we have



$$\Sigma F_x = 200\cos 37.0° - \mu n = 0 \qquad (1)$$

$$\Sigma F_y = 200\sin 37.0° + n - 400 = 0 \qquad (2)$$

$$\Sigma\tau = n(0.600 - x) - 400(0.300) + 200\sin 37.0°(0.600)$$
$$-200\cos 37.0°(0.400) = 0 \qquad (3)$$

From (2), $n = 400 - 200\sin 37.0° = 280\text{ N}$

From (3), $$x = \frac{72.2 - 120 + 260(0.600) - 64.0}{280}$$

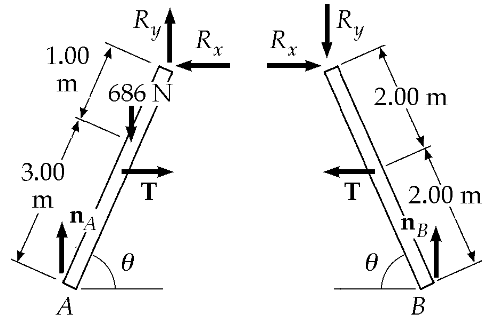
$x = \boxed{20.1\text{ cm}}$ to the left of the front edge

From (1), $$\mu_k = \frac{200\cos 37.0°}{280} = \boxed{0.571}$$

(b) In this case, locate the origin $x = 0$ at the bottom right corner of the cabinet. Since the cabinet is about to tip, we can use $\Sigma\tau = 0$ to find h:

$$\Sigma\tau = 400(0.300) - \left(300\cos 37.0°\right)h = 0 \qquad h = \frac{120}{300\cos 37.0°} = \boxed{0.501\text{ m}}$$

***10.64** From geometry, observe that



$\cos\theta = \frac{1}{4}$ and $\theta = 75.5°$

For the left half of the ladder, we have

$$\Sigma F_x = T - R_x = 0 \quad (1)$$

$$\Sigma F_y = R_y + n_A - 686\text{ N} = 0 \quad (2)$$

$$\Sigma\tau_{\text{top}} = 686\text{ N}(1.00\cos 75.5°) + T(2.00\sin 75.5°)$$

$$-n_A(4.00\cos 75.5°) = 0 \quad (3)$$

For the right half of the ladder we have

$$\Sigma F_x = R_x - T = 0$$

$$\Sigma F_y = n_B - R_y = 0 \quad (4)$$

$$\Sigma\tau_{\text{top}} = n_B(4.00\cos 75.5°) - T(2.00\sin 75.5°) = 0 \quad (5)$$

Solving equations 1 through 5 simultaneously yields:

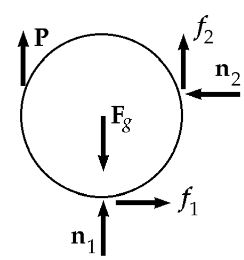
(a) $\boxed{T = 133\text{ N}}$

(b) $\boxed{n_A = 429\text{ N}}$ and $\boxed{n_B = 257\text{ N}}$

(c) $\boxed{R_x = 133\text{ N}}$ and $\boxed{R_y = 257\text{ N}}$

The force exerted by the left half of the ladder on the right half is to the right and downward.

10.65 When it is on the verge of slipping, the cylinder is in equilibrium.



$\Sigma F_x = 0$: $f_1 = n_2 = \mu_s n_1$ and $f_2 = \mu_s n_2$

$\Sigma F_y = 0$: $P + n_1 + f_2 = F_g$

$\Sigma\tau = 0$: $P = f_1 + f_2$

As P grows so do f_1 and f_2

Therefore, since $\mu_s = \frac{1}{2}$, $f_1 = \frac{n_1}{2}$ and $f_2 = \frac{n_2}{2} = \frac{n_1}{4}$

then $P + n_1 + \frac{n_1}{4} = F_g$ (1) and $P = \frac{n_1}{2} + \frac{n_1}{4} = \frac{3}{4}n_1$ (2)

So $P + \frac{5}{4}n_1 = F_g$ becomes $P + \frac{5}{4}\left(\frac{4}{3}P\right) = F_g$ or $\frac{8}{3}P = F_g$

Therefore, $P = \boxed{\frac{3}{8}F_g}$

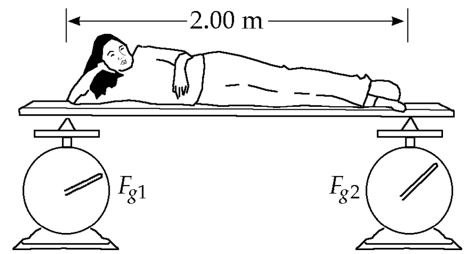
***10.66** $\Sigma F_y = 0$: $+380\text{ N} - F_g + 320\text{ N} = 0$

$F_g = 700\text{ N}$

Take torques about her feet:

$\Sigma\tau = 0$: $-380\text{ N}(2.00\text{ m}) + (700\text{ N})x + (320\text{ N})0 = 0$

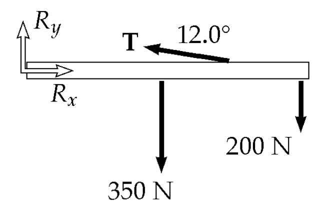
$x = \boxed{1.09\text{ m}}$



***10.67** Choosing torques about **R**, with $\Sigma\tau = 0$,

$$-\frac{L}{2}(350\text{ N}) + (T\sin 12.0°)\left(\frac{2L}{3}\right) - (200\text{ N})L = 0$$

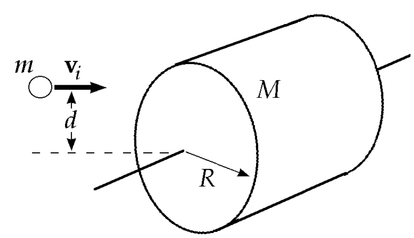
From which, $T = \boxed{2.71\text{ kN}}$



Let R_x = compression force along spine, and from $\Sigma F_x = 0$

$R_x = T_x = T\cos 12.0° = \boxed{2.65\text{ kN}}$

***10.68** (a) Consider the system to consist of the wad of clay and the cylinder. No external forces acting on this system have a torque about the center of the cylinder. Thus, angular momentum of the system is conserved about the axis of the cylinder.



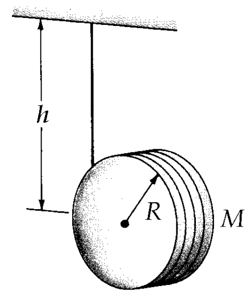
$L_f = L_i$: $I\omega = mv_id$

or $\left[\frac{1}{2}MR^2 + mR^2\right]\omega = mv_id$

Thus, $\omega = \boxed{\dfrac{2mv_id}{(M+2m)R^2}}$

(b) $\boxed{\text{No}}$. Some mechanical energy changes to internal energy in this perfectly inelastic collision.

***10.69** $\Sigma F = T - Mg = -Ma$: $\Sigma\tau = TR = I\alpha = \frac{1}{2}MR^2\left(\frac{a}{R}\right)$



(a) Combining the above two equations we find

$T = M(g-a)$ and $a = \frac{2T}{M}$ thus $\boxed{T = \frac{Mg}{3}}$

(b) $a = \frac{2T}{M} = \frac{2}{M}\left(\frac{Mg}{3}\right) = \boxed{\frac{2}{3}g}$

(c) $v_f^2 = v_i^2 + 2a(x_f - x_i)$: $v_f^2 = 0 + 2\left(\frac{2}{3}g\right)(h-0)$

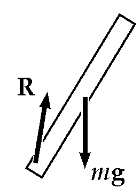
$v_f = \boxed{\sqrt{\frac{4gh}{3}}}$

For comparison, from conservation of energy for the system of the disk and the Earth we have

$U_{g\,i} + K_{rot\,i} + K_{trans\,i} = U_{g\,f} + K_{rot\,f} + K_{trans\,f}$: $Mgh + 0 + 0 = 0 + \frac{1}{2}\left(\frac{1}{2}MR^2\right)\left(\frac{v_f}{R}\right)^2 + \frac{1}{2}Mv_f^2$

$v_f = \sqrt{\frac{4gh}{3}}$

10.70 For the board just starting to move,



$\Sigma\tau = I\alpha$: $mg\left(\frac{\ell}{2}\right)\cos\theta = \left(\frac{1}{3}m\ell^2\right)\alpha$

$\alpha = \frac{3}{2}\left(\frac{g}{\ell}\right)\cos\theta$

The tangential acceleration of the end is $a_t = \ell\,\alpha = \frac{3}{2}g\cos\theta$

The vertical component is $a_y = a_t\cos\theta = \frac{3}{2}g\cos^2\theta$

If this is greater than g, the board will pull ahead of the ball falling:

(a) $\frac{3}{2}g\cos^2\theta \ge g$ gives $\cos^2\theta \ge \frac{2}{3}$ so $\cos\theta \ge \sqrt{\frac{2}{3}}$ and $\boxed{\theta \le 35.3°}$

(b) When $\theta = 35.3°$, the cup will land underneath the release-point of the ball if $r_c = \ell\cos\theta$

When $\ell = 1.00$ m, and $\theta = 35.3°$ $r_c = 1.00\text{ m}\sqrt{\frac{2}{3}} = 0.816$ m

so the cup should be $(1.00\text{ m} - 0.816\text{ m}) = \boxed{0.184\text{ m from the moving end}}$

***10.71** Consider the total weight of each hand to act at the center of gravity (mid-point) of that hand. Then the total torque (taking CCW as positive) of these hands about the center of the clock is given by

$$\tau = -m_h g\left(\frac{L_h}{2}\right)\sin\theta_h - m_m g\left(\frac{L_m}{2}\right)\sin\theta_m = -\frac{g}{2}\left(m_h L_h \sin\theta_h + m_m L_m \sin\theta_m\right)$$

If we take $t = 0$ at 12 o'clock, then the angular positions of the hands at time t are

$$\theta_h = \omega_h t,$$

where $\omega_h = \frac{\pi}{6}$ rad/h

and $\theta_m = \omega_m t,$

where $\omega_m = 2\pi$ rad/h

Therefore, $\tau = -4.90\ \text{m/s}^2\left[60.0\ \text{kg}(2.70\ \text{m})\sin(\pi t/6) + 100\ \text{kg}(4.50\ \text{m})\sin 2\pi t\right]$

or $\tau = -794\ \text{N}\cdot\text{m}\left[\sin(\pi t/6) + 2.78\sin 2\pi t\right]$, where t is in hours.

(a) (i) At 3:00, $t = 3.00$ h,

so $\tau = -794\ \text{N}\cdot\text{m}\left[\sin(\pi/2) + 2.78\sin 6\pi\right] = \boxed{-794\ \text{N}\cdot\text{m}}$

(ii) At 5:15, $t = 5\ \text{h} + \frac{15}{60}\ \text{h} = 5.25\ \text{h}$, and substitution gives:

$\tau = \boxed{-2510\ \text{N}\cdot\text{m}}$

(iii) At 6:00, $\tau = \boxed{0\ \text{N}\cdot\text{m}}$

(iv) At 8:20, $\tau = \boxed{-1160\ \text{N}\cdot\text{m}}$

(v) At 9:45, $\tau = \boxed{-2940\ \text{N}\cdot\text{m}}$

(b) The total torque is zero at those times when

$$\sin(\pi t/6) + 2.78\sin 2\pi t = 0$$

We proceed numerically, to find 0, 0.5152955, ..., corresponding to the times

12:00:00	12:30:55	12:58:19	1:32:31	1:57:01
2:33:25	2:56:29	3:33:22	3:56:55	4:32:24
4:58:14	5:30:52	6:00:00	6:29:08	7:01:46
7:27:36	8:03:05	8:26:38	9:03:31	9:26:35
10:02:59	10:27:29	11:01:41	11:29:05	

ANSWERS TO EVEN NUMBERED PROBLEMS

2. (a) 1 200 rad/s (b) 25.0 s

4. (a) 5.00 rad, 10.0 rad/s, $4.00\ \text{rad/s}^2$ (b) 53.0 rad, 22.0 rad/s, $4.00\ \text{rad/s}^2$

6. $13.7\ \text{rad/s}^2$

8. $\sim 10^7$ rev/yr

10. (a) 56.5 rad/s (b) 22.4 rad/s (c) $-7.63\ \text{mrad/s}^2$
(d) 177 krad (e) 5.81 km

12. (a) 8.00 rad/s (b) 8.00 m/s, $64.1\ \text{m/s}^2$ at 3.58° ahead of the radius
(c) 9.00 rad

14. 1.04×10^{-3} J

16. $v = \left[\dfrac{2(m_1 - m_2)gh}{m_1 + m_2 + I/R^2}\right]^{1/2}, \quad \omega = \left[\dfrac{2(m_1 - m_2)gh}{m_1 R^2 + m_2 R^2 + I}\right]^{1/2}$

18. 168 N·m (clockwise)

20. (a) 168° (b) 11.9°
(c) Only the first method gives unambiguous results.

22. See the solution

24. 2.94 kN on each rear wheel and 4.41 kN on each front wheel

26. (a) 1.04 kN at 60.0° (b) (370**i** + 900 **j**) N

28. $F_{Ax} = 6.47 \times 10^5$ N (left), $F_{Bx} = 6.47 \times 10^5$ N (right), $F_{Ay} = 1.27 \times 10^5$ N (up), $F_{By} = 0$ N

30. (a) $21.6\ \text{kg}\cdot\text{m}^2$ (b) 3.60 N·m (c) 52.4 rev

32. 0.312

34. (a) 1.59 m/s (b) 53.1 rad/s

36. 190 rad/s

38. (a) $9.03\times10^{9}\ \text{km}\cdot\text{m}^2/\text{s}$ (south) (b) No (c) zero

40. $1.20\ \text{kg}\cdot\text{m}^2/\text{s}$

42. (a) 3.14 N·m (b) (0.400 kg·m) v (c) $7.85\ \text{m/s}^2$

44. (a) 1.91 rad/s (b) 2.53 J, 6.44 J

46. (a) $7.20\times10^{-3}\ \text{kg}\cdot\text{m}^2/\text{s}$ (b) 9.47 rad/s

48. 5.99×10^{-2} J

50. $v_{\text{disk}}=\sqrt{\dfrac{4gh}{3}}$, $v_{\text{ring}}=\sqrt{gh}$, the disk

52. (a) 2.38 m/s See the solution. (b) 4.31 m/s
(c) The ball does not reach the top of the loop.

54. $5.45\times10^{22}\ \text{N}\cdot\text{m}$

56. (a) Mvd (b) Mv^2 (c) Mvd
(d) $2v$ (e) $4Mv^2$ (f) $3Mv^2$

58. (a) 0.992 W (b) 827 W

60. (a) $\sqrt{\dfrac{2mgd\sin\theta+kd^2}{I+mR^2}}$ (b) 1.74 rad/s

62. (a) 61.2 J (b) 50.8 J

64. (a) 133 N (b) $n_A=429$ N and $n_B=257$ N
(c) $R_x=133$ N right and $R_y=257$ N downward

66. 1.09 m

68. (a) $\omega=2mv_id/(M+2m)R^2$ (b) No; some mechanical energy changes into internal energy

70. See the solution