CHAPTER 8

1\. (*a*) 30° = (30°)(π rad/180°) = ¹/6 rad = 0.524 rad;

(*b*) 57° = (57°)(¹ rad/180°) = 19¹/60 = 0.995 rad;

(*c*) 90° = (90°)(¹ rad/180°) = ¹/2 = 1.571 rad;

(*d*) 360° = (360°)(¹ rad/180°) = 2¹ = 6.283 rad;

(*e*) 420° = (420°)(¹ rad/180°) = 7¹/3 = 7.330 rad.

2\. The subtended angle in radians is the size of the object divided by the distance to the object:

$\theta = 2R_{Sun}/r$;

(0.5°)(¹ rad/180°) = $2R_{Sun}$/(150 ∞ 10$_6$ km), which gives R_{Sun} = 6.5 ∞ 10$_5$ km.

3\. The subtended angle in radians is the size of the object divided by the distance to the object:

$\theta_{Sun} = 2R_{Sun}/r_{Sun}$ = 2(6.96 ∞ 10$_5$ km)/(149.6 ∞ 10$_6$ km) = 9.30 ∞ 10—$_3$ rad (0.53°);

$\theta_{Moon} = 2R_{Moon}/r_{Moon}$ = 2(1.74 ∞ 10$_3$ km)/(384 ∞ 10$_3$ km) = 9.06 ∞ 10—$_3$ rad (0.52°).

4\. We find the distance from

$\theta = h/r$;

(6°)(¹ rad/180°) = (300 m)/r; which gives r = 2.9 ∞ 10$_3$ m.

5\. We find the diameter of the spot from

$\theta = D_{spot}/r$;

(1.8 ∞ 10—$_5$ rad) = D_{spot}/(380 ∞ 10$_3$ km), which gives D_{spot} = 6.8 km.

6\. ω = (1800 rev/min)(2¹ rad/rev)(1 min/60 s) = 188 rad/s.

7\. The linear speed of the point on the edge is the tangential speed:

$v = r\omega$ = (0.175 m)(188 rad/s) = 33 m/s.

Because the speed is constant, the tangential acceleration is zero. There will be a radial acceleration:

$a_R = \omega_2 R$ = (188 rad/s)$_2$(0.175 m) = 6.2 ∞ 10$_3$ m/s$_2$.

8\. From the definition of angular acceleration, we have

α = Æω/Æt = [(33 rev/min)(2¹ rad/rev)(1 min/60 s) — 0]/(1.8 s) = 1.9 rad/s2.

9. From the definition of angular velocity, we have

$\omega = \Delta\theta/\Delta t$, and we use the time for each hand to turn through a complete circle, 2¹ rad.

(*a*) $\omega_{\text{second}} = \Delta\theta/\Delta t$

= (2¹ rad)/(60 s) = 0.105 rad/s.

(*b*) $\omega_{\text{minute}} = \Delta\theta/\Delta t$

= (2¹ rad)/(60 min)(60 s/min) = 1.75 ∞ 10—3 rad/s.

(*c*) $\omega_{\text{hour}} = \Delta\theta/\Delta t$

= (2¹ rad)/(12 h)(60 min/h)(60 s/min) = 1.45 ∞ 10—4 rad/s.

(*d*) For each case, the angular velocity is constant, so the angular acceleration is zero.

10. From the definition of angular acceleration, we have

α = Æω/Æt = [0 — (7500 rev/min)(2¹ rad/rev)(1 min/60 s)]/(3.0 s) = — 2.6 ∞ 102 rad/s2.

11. In each revolution the ball rolls a distance equal to its circumference, so we have

L = N(¹D);

4.5 m = (15.0)¹D, which gives D = 0.095 m = 9.5 cm.

12. In each revolution the wheel rolls a distance equal to its circumference, so we have

L = N(¹D);

7.0 ∞ 103 m = N¹(0.68 m), which gives N = 3.3 ∞ 103 revolutions.

13. The subtended angle in radians is the size of the object divided by the distance to the object. A pencil with a diameter of 6 mm will block out the Moon if it is held about 60 cm from the eye. For the angle subtended we have $\theta_{\text{Moon}} = D_{\text{pencil}}/r_{\text{pencil}}$ Å (0.6 cm)/(60 cm) Å 0.01 rad.

We estimate the diameter of the Moon from

$\theta_{\text{Moon}} = D_{\text{Moon}}/r_{\text{Moon}}$;

0.01 rad = D_{Moon}/(3.8 ∞ 105 km), which gives D_{Moon} Å 3.8 ∞ 103 km.

14. (*a*) The Earth moves one revolution around the Sun in one year, so we have

$\omega_{\text{orbit}} = \Delta\theta/\Delta t$

= $(2^{1}$ rad)/(1 yr)(3.16 ∞ 10_{7} s/yr) = 1.99 ∞ $10—_{7}$ rad/s.

(*b*) The Earth rotates one revolution in one day, so we have

$\omega_{rotation} = \Delta\theta/\Delta t$

= $(2^{1}$ rad)/(1 day)(24 h/day)(3600 s/h) = 7.27 ∞ $10—_{5}$ rad/s.

15. All points will have the angular speed of the Earth:

$\omega = \Delta\theta/\Delta t$ = $(2^{1}$ rad)/(1 day)(24 h/day)(3600 s/h) = 7.27 ∞ $10—_{5}$ rad/s.

Their linear speed will depend on the distance from the rotation axis.

(*a*) On the equator we have

$v = R_{Earth}\omega$ = (6.38 ∞ 10_{6} m)(7.27 ∞ $10—_{5}$ rad/s) = 464 m/s.

(*b*) At a latitude of 66.5° the distance is R_{Earth} cos 66.5°, so we have

$v = R_{Earth}$ cos 66.5° ω = (6.38 ∞ 10_{6} m)(cos 66.5°)(7.27 ∞ $10—_{5}$ rad/s) = 185 m/s.

(*c*) At a latitude of 45.0° the distance is R_{Earth} cos 45.0°, so we have

$v = R_{Earth}$ cos 45.0° ω = (6.38 ∞ 10_{6} m)(cos 45.0°)(7.27 ∞ $10—_{5}$ rad/s) = 328 m/s.

16. The particle will experience a radial acceleration:

$a_R = \omega_2 r$;

(100,000)(9.80 m/s_2) = ω_2(0.070 m), which gives

ω = (3740 rad/s)(60 s/min)/$(2^{1}$ rad/rev) = 3.6 ∞ 10_{4} rpm.

17. The initial and final angular speeds are

ω_0 = (160 rpm)$(2^{1}$ rad/rev)/(60 s/min) = 16.8 rad/s;

ω = (280 rpm)$(2^{1}$ rad/rev)/(60 s/min) = 29.3 rad/s.

(*a*) We find the angular acceleration from

α = Æω/Æt

= (29.3 rad/s — 16.8 rad/s)/(4.0 s) = 3.1 rad/s_2.

(*b*) We find the angular speed after 2.0 s:

$\omega = \omega_0 + \alpha t$ = 16.8 rad/s + (3.13 rad/s_2)(2.0 s) = 23.1 rad/s.

At this time the radial acceleration of a point on the rim is

$a_R = \omega_2 r$ = (23.1 rad/s)$_2$(0.35 m) = 1.9 ∞ 10_{2} m/s_2.

The tangential acceleration is

$a_{tan} = \alpha r$ = (3.13 rad/s2)(0.35 m) = 1.1 m/s2.

18. If there is no slipping, the tangential speed of the outer edge of the turntable is the tangential speed of the outer edge of the roller:

$v = R_1\omega_1 = R_2\omega_2$, which gives $\omega_1/\omega_2 = R_2/R_1$.

19. The final angular speed is

ω = (1 rpm)(2^1 rad/rev)/(60 s/min) = 0.105 rad/s.

(*a*) We find the angular acceleration from

α = Æω/Æt

= (0.105 rad/s — 0)/(10.0 min)(60 s/min) = 1.8 ∞ 10—4 rad/s2.

(*b*) We find the angular speed after 5.0 min:

$\omega = \omega_0 + \alpha t$ = 0 + (1.8 ∞ 10—4 rad/s2)(5.0 min)(60 s/min) = 5.45 ∞ 10—2 rad/s.

At this time the radial acceleration of a point on the skin is

$a_R = \omega_2 r$ = (5.45 ∞ 10—2 rad/s)2(4.25 m) = 1.2 ∞ 10—2 m/s2.

The tangential acceleration is

$a_{tan} = \alpha r$ = (1.8 ∞ 10—4 rad/s2)(4.25 m) = 7.7 ∞ 10—4 m/s2.

20. For motion with constant angular acceleration we use

$\omega_2 = \omega_{02} + 2\alpha\theta$;

[(33 rpm)(2^1 rad/rev)/(60 s/min)]2 = 0 + 2α (1.7 rev)(2^1 rad/rev), which gives α = 0.56 rad/s2.

21. For the angular displacement we use

θ = !($\omega_0 + \omega$)t

= ![0 + (15,000 rpm)(2^1 rad/rev)/(60 s/min)](220 s) = 1.73 ∞ 105 rad.

Thus θ = (1.73 ∞ 105 rad)/(2^1 rad/rev) = 2.75 ∞ 104 rev.

22. (*a*) For motion with constant angular acceleration we use

$\omega = \omega_0 + \alpha t$;

(1200 rev/min)(2^1 rad/rev)(1 min/60s) = (4000 rev/min)(2^1 rad/rev)(1 min/60s) + α (3.5 s), which gives $\alpha = —84$ rad/s^2.

(*b*) For the angular displacement we use

$\theta = !(\omega_0 + \omega)t$

$= ![(4000$ rev/min + 1200 rev/min)][(2^1 rad/rev)/(60 s/min)](3.5 s) = 954 rad.

Thus $\theta =$ (954 rad)/(2^1 rad/rev) = 1.5 ∞ 10^2 rev.

23. (*a*) We find the angular acceleration from

$\theta = \omega_0 t + !\alpha t^2$;

(20 rev)(2^1 rad/rev) = 0 + $!\alpha$[(1 min)(60 s/min)]^2, which gives $\alpha = 0.070$ rad/s^2.

(*b*) We find the final angular speed from

$\omega = \omega_0 + \alpha t = 0 + (0.070$ rad/s^2)(60 s) = 4.2 rad/s = 40 rpm.

24. We find the total angle the wheel turns from

$\theta = !(\omega_0 + \omega)t$

$= ![(210$ rev/min + 350 rev/min)][(2^1 rad/rev)/(60 s/min)](6.5 s) = 191 rad = 30.3 rev.

For each revolution the point on the edge will travel one circumference, so the total distance traveled is

$d = \theta D$ = (30.3 rev)^1(0.40 m) = 38 m.

25. We use the initial conditions of $t = 0$, $\theta_0 = 0$, and ω_0. If the angular acceleration is constant, the average angular acceleration is also the instantaneous angular acceleration. From the definition of angular acceleration, we have

$\alpha = \alpha_{av} = Æ\omega/Æt = (\omega — \omega_0)/(t — 0)$, which gives $\omega = \omega_0 + \alpha t$; Eq. (8—9a).

Because the angular velocity is a linear function of the time, the average velocity will be

$\omega_{av} = !(\omega_0 + \omega)$; Eq. (8—9d).

From the definition of angular velocity, we have

$\omega = \omega_{av} = Æ\theta/Æt$;

$!(\omega_0 + \omega) = (\theta — 0)/(t — 0)$, which gives $t = 2\theta/(\omega + \omega_0)$, or $\omega = — \omega_0 + 2\theta/t$.

When we substitute the expression for t in Eq. (8—9a), we get

$\omega — \omega_0 = \alpha[2\theta/(\omega + \omega_0)]$, which simplifies to $\omega^2 = \omega_0^2 + 2\alpha\theta$, Eq. (8—9c).

When we substitute the expression for ω in Eq. (8—9a), we get

$— \omega_0 + 2\theta/t = \omega_0 + \alpha t$, which simplifies to $\theta = \omega_0 t + !\alpha t^2$; Eq. (8—9b).

26. (*a*) If there is no slipping, the linear tangential acceleration of the pottery wheel and the rubber wheel must be the same:

$a_{tan} = R_1\alpha_1 = R_2\alpha_2$;

(2.0 cm)(7.2 rad/s^2) = (25.0 cm)α_2, which gives α_2 = 0.58 rad/s^2.

(*b*) We find the time from

$\omega = \omega_0 + \alpha t$;

(65 rev/min)(2^1 rad/rev)/(60 s/min) = 0 + (0.58 rad/s^2)t, which gives t = 12 s.

27. We find the initial and final angular velocities of the wheel from the rolling condition:

$\omega_0 = v_0/r$ = [(100 km/h)/(3.6 ks/h)]/(0.40 m) = 69.5 rad/s;

$\omega = v/r$ = [(50 km/h)/(3.6 ks/h)]/(0.40 m) = 34.8 rad/s.

(*a*) We find the angular acceleration from

$\omega^2 = \omega_0^2 + 2\alpha\theta$;

(69.5 rad/s)^2 = (34.8 rad/s)^2 + 2α (65 rev)(2^1 rad/rev), which gives $\alpha = —$ 4.4 rad/s^2.

(*b*) We find the additional time from

$\omega_{final} = \omega + \alpha t$;

0 = 34.8 rad/s + (— 4.4 rad/s^2)t, which gives t = 7.9 s.

28. (*a*) The tangential acceleration is

$a_{tan} = \alpha r$.

The angular speed as a function of time is

$\omega = \omega_0 + \alpha t = 0 + \alpha t = \alpha t$.

The radial acceleration is

$a_R = \omega^2 r = (\alpha t)^2 r = \alpha^2 t^2 r$.

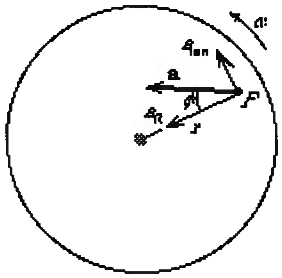
(*b*) Because each revolution corresponds to an angular displacement of 2^1, the number of revolutions as a function of time is

$N = \theta/2^1 = (\omega_0 t + ! \alpha t^2)/2^1 = \alpha t^2/4^1$.

From the figure we see that

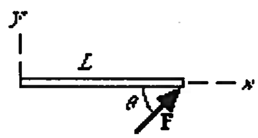
$\tan\phi = a_{tan}/a_R = \alpha r/\alpha^2 t^2 r = 1/\alpha t^2 = 1/4^1 N$, or

$\phi = \tan^{—1}(1/4^1 N)$.



29. The force being applied by the rider is equal to his force of gravity. The maximum torque will be exerted when this force is perpendicular to the line from the axis to the pedal:

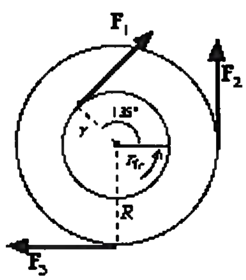
$\tau_{max} = rF = (0.17\text{ m})(55\text{ kg})(9.80\text{ m/s}^2) = 92\text{ m}\cdot\text{N}$.



30. If θ is the angle between the force and the surface of the door, we have

(*a*) $\tau = LF\sin\theta = (0.84\text{ m})(45\text{ N})\sin 90° = 38\text{ m}\cdot\text{N}$.

(*b*) $\tau = LF\sin\theta = (0.84\text{ m})(45\text{ N})\sin 60° = 33\text{ m}\cdot\text{N}$.



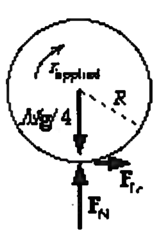
31. We assume clockwise motion, so the frictional torque is counterclockwise.

If we take the clockwise direction as positive, we have

$\tau_{net} = rF_1 — RF_2 + RF_3 — \tau_{fr}$

= (0.10 m)(35 N) — (0.20 m)(30 N) + (0.20 m)(20 N) — 0.40 m · N

= 1.1 m · N (clockwise).



32. Each wheel supports one-quarter of the weight. For the wheels to spin, the applied torque must be greater than the maximum frictional torque produced by the static friction from the pavement:

$\tau_{applied}$ ³ $F_{fr}r = \mu_s F_N r$ = (0.75)#(1080 kg)(9.80 m/s²)(0.33 m)

³ 6.5 ∞ 10² m · N.

33. The force to produce the required torque is

$F_{wrench} = \tau/L$ = (80 m · N)/(0.30 m) = 2.7 ∞ 10² N.

Because this torque is balanced by the torque produced by the bolt on the wrench, an equal torque is produced on the bolt. Because there are six points where a force is applied to the bolt, we have

$F_{bolt} = (\tau/r)/6 = (80\ \mathrm{m \cdot N})/6(0.0075\ \mathrm{m}) = 1.8 \infty 10^3\ \mathrm{N}$.

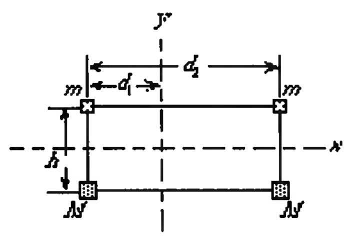
34. The moment of inertia of a sphere about an axis through its center is

$I = (2/5)MR^2 = (2/5)(12.2\ \mathrm{kg})(0.623\ \mathrm{m})^2 = 1.89\ \mathrm{kg \cdot m^2}$.

35. Because all of the mass is the same distance from the axis, we have

$I = MR^2 = (1.25\ \mathrm{kg})[!(0.667\ \mathrm{m})]^2 = 0.139\ \mathrm{kg \cdot m^2}$.

The mass of the hub can be ignored because the distance of its mass from the axis is so small.



36. (*a*) For the moment of inertia about the *y*-axis, we have

$I_a = \cdot m_i R_i^2 = md_1^2 + Md_1^2 + m(d_2 - d_1)^2 + M(d_2 - d_1)^2$

$= (1.8\ \mathrm{kg})(0.50\ \mathrm{m})^2 + (3.1\ \mathrm{kg})(0.50\ \mathrm{m})^2 +$

$(1.8\ \mathrm{kg})(1.00\ \mathrm{m})^2 + (3.1\ \mathrm{kg})(1.00\ \mathrm{m})^2$

$= 6.1\ \mathrm{kg \cdot m^2}$.

(*b*) For the moment of inertia about the *x*-axis, all the masses

are the same distance from the axis, so we have

$I_b = \cdot m_i R_i^2 = (2m + 2M)(!h)^2$

$= [2(1.8\ \mathrm{kg}) + 2(3.1\ \mathrm{kg})](0.25\ \mathrm{m})^2 = 0.61\ \mathrm{kg \cdot m^2}$.

37. If *M* is the total mass and *D* is the effective separation, each atom has a mass $!M$ and is $!D$ from the axis. We find the distance *D* from

$I = 2(!M)(!D)^2 = \#MD^2$;

$1.9 \infty 10^{-46}\ \mathrm{kg \cdot m^2} = \#(5.3 \infty 10^{-26}\ \mathrm{kg})D^2$, which gives $D = 1.2 \infty 10^{-10}\ \mathrm{m}$.

38. (*a*) Because we can ignore the mass of the rod, for the moment of inertia we have

$I = m_{ball}R^2$

$= (1.05\ \mathrm{kg})(0.900\ \mathrm{m})^2 = 0.851\ \mathrm{kg \cdot m^2}$.

(*b*) To produce constant angular velocity, the net torque must be zero:

$\tau_{net} = \tau_{applied} - \tau_{friction} = 0$, or

$\tau_{applied} = F_{fr}R = (0.0800\ \mathrm{N})(0.900\ \mathrm{m}) = 0.0720\ \mathrm{m \cdot N}$.

39. We find the required constant angular acceleration from

$\omega = \omega_0 + \alpha t$;

(30 rev/min)(2¹ rad/rev)(1 min/60s) = 0 + α (5.0 min)(60 s/min), which gives α = 0.0105 rad/s_2.

The moment of inertia of the solid cylinder is !MR_2. Because we have four forces creating the torque that produces the required acceleration, we have

$\tau = I\alpha$;

4FR = !$MR_2\alpha$, or

$F = MR\alpha/8$ = (2600 kg)(3.0 m)(0.0105 rad/s_2)/8 = 10 N.

40. (*a*) The moment of inertia of the solid cylinder is

I = !MR_2 = !(0.550 kg)(0.0850 m)$_2$ = 1.99 ∞ 10—$_3$ kg · m$_2$.

(*b*) We can find the frictional torque acting on the wheel from the slowing-down motion:

$\tau_{fr} = I\alpha_1 = I(\omega_1 — \omega_{01})/t_1$

= (1.99 ∞ 10—$_3$ kg · m$_2$)[0 — (1500 rpm)(2¹ rad/rev)/(60 s/min)]/(55.0 s) = — 5.67 ∞ 10—$_3$ m · N.

For the accelerating motion, we have

$\tau_{applied} + \tau_{fr} = I\alpha_2 = I(\omega_2 — \omega_{02})/t_2$;

$\tau_{applied}$ — 5.67 ∞ 10—$_3$ m · N = (1.99 ∞ 10—$_3$ kg · m$_2$)[(1500 rpm)(2¹ rad/rev)/(60 s/min) — 0]/(5.00 s),

which gives

$\tau_{applied}$ = 6.82 ∞ 10—$_2$ m · N.

41. For the accelerating motion, we have

$\tau_{applied} = I\alpha = I(\omega — \omega_0)/t$ = @$mL_2(\omega — \omega_0)/t$

= @(2.2 kg)(0.95 m)$_2$[(3.0 rev/s)(2¹ rad/rev) — 0]/(0.20 s) = 62 m · N.

42. The moment of inertia for the system of merry-go-round and children about the center is

I = !MR_2 + 2$m_{child}R_2$ = (!M + 2m_{child})R_2 = [!(800 kg) + 2(25 kg)](2.5 m)$_2$ = 2.81 ∞ 10$_3$ kg · m$_2$.

We find the torque required from

$\tau_{applied} = I\alpha = I(\omega — \omega_0)/t$

= (2.81 ∞ 10$_3$ kg · m$_2$)[(20 rpm)(2¹ rad/rev)/(60 s/min) — 0]/(10.0 s) = 5.9 ∞ 10$_2$ m · N.

Because the worker is pushing perpendicular to the radius, the required force is

$F = \tau_{applied}/R = (5.9 \infty 10_2\ \mathrm{m \cdot N})/(2.5\ \mathrm{m}) = 2.4 \infty 10_2\ \mathrm{N}$.

43. We find the acceleration from

$\tau_{friction} = I\alpha = !MR_2\alpha$;

$— 1.20\ \mathrm{m \cdot N} = !(4.80\ \mathrm{kg})(0.0710\ \mathrm{m})_2\alpha$, which gives $\alpha = — 99.2\ \mathrm{rad/s_2}$.

We find the angle turned through from

$\omega_2 = \omega_{02} + 2\alpha\theta$;

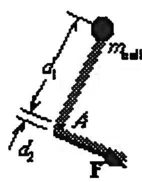
$0 = [(10{,}000\ \mathrm{rpm})(2^{1}\ \mathrm{rad/rev})/(60\ \mathrm{s/min})]_2 + 2(— 99.2\ \mathrm{rad/s_2})\theta$, which gives

$\theta = 5.53 \infty 10_3\ \mathrm{rad} = 8.80 \infty 10_2\ \mathrm{rev}$.

We can find the time from

$\omega = \omega_0 + \alpha t$;

$0 = (10{,}000\ \mathrm{rev/min})(2^{1}\ \mathrm{rad/rev})/(60\ \mathrm{s/min}) + (— 99.2\ \mathrm{rad/s_2})t$; which gives $t = 10.6$ s.



44. (*a*) Because we ignore the mass of the arm, for the moment of inertia we have

$I = m_{ball}d_{12} = (3.6\ \mathrm{kg})(0.30\ \mathrm{m})_2 = 0.324\ \mathrm{kg \cdot m_2}$.

The angular acceleration of the ball-arm system is

$\alpha = a_{tan}/d_1 = (7.0\ \mathrm{m/s_2})/(0.30\ \mathrm{m}) = 23.3\ \mathrm{rad/s_2}$.

Thus we find the required torque from

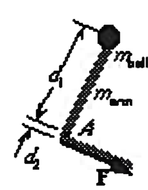
$\tau = I\alpha$

$= (0.324\ \mathrm{kg \cdot m_2})(23.3\ \mathrm{rad/s_2}) = 7.5\ \mathrm{m \cdot N}$.

(*b*) Because the force from the triceps muscle is perpendicular to the line from the axis, we find the force from

$F = \tau/d_2 = (7.5\ \mathrm{m \cdot N})/(0.025\ \mathrm{m}) = 3.0 \infty 10_2\ \mathrm{N}$.

45. (*a*) The final angular velocity of the arm and ball is



$\omega = v/d_1 = (10.0\ \mathrm{m/s})/(0.30\ \mathrm{m}) = 33.3\ \mathrm{rad/s}$.

We find the angular acceleration from

$\omega = \omega_0 + \alpha t$;

$33.3\ \mathrm{rad/s} = 0 + \alpha(0.350\ \mathrm{s})$, which gives $\alpha = 95.2\ \mathrm{rad/s_2}$.

(*b*) For the moment of inertia of the ball and arm we have

$I = m_{\text{ball}}d_1{}^2 + @m_{\text{arm}}d_1{}^2$

$= (1.50\text{ kg})(0.30\text{ m})^2 + @(3.70\text{ kg})(0.30\text{ m})^2 = 0.246\text{ kg} \cdot \text{m}^2.$

Because the force from the triceps muscle is perpendicular

to the line from the axis, we find the force from

$F = \tau/d_2 = I\alpha/d_2 = (0.246\text{ kg} \cdot \text{m}^2)(95.2\text{ rad/s}^2)/(0.025\text{ m}) = 9.4 \infty 10^2\text{ N}.$

46. For the moment of inertia of the rotor blades we have

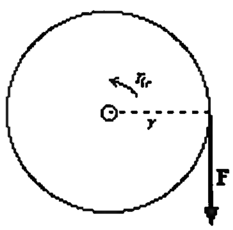
$I = 3(@m_{\text{blade}}L^2) = m_{\text{blade}}L^2 = (160\text{ kg})(3.75\text{ m})^2 = 2.25 \infty 10^3\text{ kg} \cdot \text{m}^2.$

We find the required torque from

$\tau = I\alpha = I(\omega - \omega_0)/t$

$= (1.99 \infty 10^{-3}\text{ kg} \cdot \text{m}^2)[(5.0\text{ rev/s})(2^1\text{ rad/rev}) - 0]/(8.0\text{ s}) = 8.8 \infty 10^3\text{ m} \cdot \text{N}.$

47. We choose the clockwise direction as positive.



(*a*) With the force acting, we write $\Sigma\tau = I\alpha$ about the axis

from the force diagram for the roll:

$Fr - \tau_{\text{fr}} = I\alpha_1;$

$(3.2\text{ N})(0.076\text{ m}) - 0.11\text{ m} \cdot \text{N} = (2.9 \infty 10^{-3}\text{ kg} \cdot \text{m}^2)\alpha_1,$

which gives $\alpha_1 = 45.9\text{ rad/s}^2$.

We find the angle turned while the force is acting from

$\theta_1 = \omega_0 t + !\alpha_1 t_1{}^2$

$= 0 + !(45.9\text{ rad/s}^2)(1.3\text{ s})^2 = 38.8\text{ rad}.$

The length of paper that unrolls during this time is

$s_1 = r\theta_1 = (0.076\text{ m})(38.8\text{ rad}) = 2.9\text{ m}.$

(*b*) With no force acting, we write $\Sigma\tau = I\alpha$ about the axis

from the force diagram for the roll:

$-\tau_{\text{fr}} = I\alpha_2;$

$-0.11\text{ m} \cdot \text{N} = (2.9 \infty 10^{-3}\text{ kg} \cdot \text{m}^2)\alpha_2,$

which gives $\alpha_2 = -37.9\text{ rad/s}^2$.

The initial velocity for this motion is the final velocity from part (*a*):

$\omega_1 = \omega_0 + \alpha_1 t_1 = 0 + (45.9\text{ rad/s}^2)(1.3\text{ s}) = 59.7\text{ rad/s}.$

We find the angle turned after the force is removed from

$\omega_2^2 = \omega_1^2 + 2\alpha_2\theta_2$;

$0 = (59.7\text{ rad/s})^2 + 2(-37.9\text{ rad/s}^2)\theta_2$, which gives $\theta_2 = 47.0$ rad.

The length of paper that unrolls during this time is

$s_2 = r\theta_2 = (0.076\text{ m})(47.0\text{ rad}) = 3.6$ m.

48. We assume that $m_2 > m_1$ and choose the coordinates shown on the force diagrams. Note that we take the positive direction in the direction of the acceleration for each object. Because the linear acceleration of the masses is the tangential acceleration of the rim of the pulley, we have

$a = a_{tan} = \alpha R_0$.

We write $\Sigma F_y = ma_y$ for m_2:

$m_2 g - F_{T2} = m_2 a$.

We write $\Sigma F_y = ma_y$ for m_1:

$F_{T1} - m_1 g = m_1 a$.

We write $\Sigma\tau = I\alpha$ for the pulley about its axle:

$F_{T2}R_0 - F_{T1}R_0 = I\alpha = Ia/R_0$, or $F_{T2} - F_{T1} = Ia/R_0^2$.

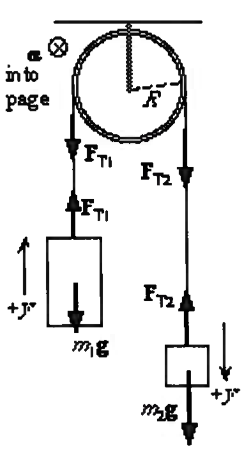
If we add the two force equations, we get

$F_{T1} - F_{T2} = (m_1 + m_2)a + (m_1 - m_2)g$.

When we add these two equations, we get

$a = (m_2 - m_1)g/(m_1 + m_2 + I/R_0^2)$.

If the moment of inertia of the pulley is ignored, from the torque



equation, we see that the two tensions will be equal.

For the acceleration, we set $I = 0$ and get

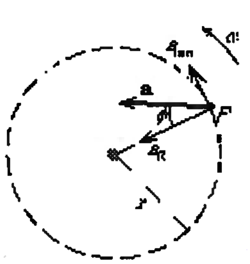
$a_0 = (m_2 - m_1)g/(m_1 + m_2)$.

Thus we see that $a_0 > a$.

49. (*a*) The final angular velocity of the hammer is

$\omega = v/r = (28.0\text{ m/s})/(1.20\text{ m}) = 23.3$ rad/s.

We find the angular acceleration from



$\omega 2 = \omega 02 + 2\alpha\theta;$

(23.3 rad/s)2 = 0 + 2α (4 rev)(2¹ rad/rev),

which gives α = 10.8 rad/s2.

(*b*) For the tangential acceleration we have

$a$tan = αr = (10.8 rad/s2)(1.20 m) = 13.0 m/s2.

(*c*) For the radial acceleration at release we have

aR = $\omega 2r$ = (23.3 rad/s)2(1.20 m) = 653 m/s2.

(*d*) The magnitude of the resultant acceleration of the hammer is

a = ($a$tan2 + aR2)1/2 = [(13.0 m/s2)2 + (653 m/s2)2]1/2 = 653 m/s2.

This acceleration is provided by the net force exerted on the hammer, so we have

Fnet = ma = (7.30 kg)(653 m/s2) = 4.77 ∞ 103 N.

(*e*) We find the angle from

tan ϕ = $a$tan/aR = (13.0 m/s2)/(653 m/s2) = 0.0199, which gives ϕ = 1.14°.

50. The angular speed of the cylinder is $\omega = v/R$. The total kinetic energy will have a translational term for the center of mass and a term for the rotational energy about the center of mass:

ketotal = ketrans + kerot = !*Mv*2 + !*I*ω2 = !*Mv*2 + !(^*MR*2)(*v*/*R*)2 = 7*Mv*2/10

= 7(7.3 kg)(4.3 m)2/10 = 94 J.

51. The work done increases the kinetic energy of the rotor:

W = Æke = !*I*ω2 — 0

= !(3.15 ∞ 10—2 kg · m2)[(8000 rev/min)(2¹ rad/rev)/(60 s/min)]2 = 1.11 ∞ 104 J.

52. (*a*) The Earth rotates one revolution in one day, so we have

ωrotation = $\Delta\theta/\Delta t$

= (2¹ rad)/(1 day)(24 h/day)(3600 s/h) = 7.27 ∞ 10—5 rad/s.

The kinetic energy of rotation is

kerotation = !*I*rotationωrotation2 = !(^*Mr*2)ωrotation2

= !(^)(6.0 ∞ 1024 kg)(6.4 ∞ 106 m)2(7.27 ∞ 10—5 rad/s)2 = 2.6 ∞ 1029 J.

(*b*) The Earth moves one revolution around the Sun in one year, so we have

ωorbit = $\Delta\theta/\Delta t$

= (2¹ rad)/(1 yr)(3.16 ∞ 107 s/yr) = 1.99 ∞ 10—7 rad/s.

The kinetic energy of revolution is

$ke_{revolution}$ = !$I_{revolution}\omega_{revolution}$2 = !($MR$2)$\omega_{revolution}$2

= !(6.0 ∞ 1024 kg)(1.5 ∞ 1011 m)2(1.99 ∞ 10—7 rad/s)2 = 2.7 ∞ 1033 J.

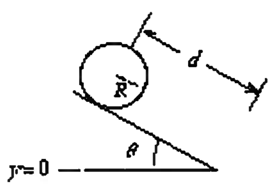
We see that the kinetic energy of revolution is much greater than that of rotation, so the total energy is

ke_{total} = 2.7 ∞ 1033 J.

53. The work done increases the kinetic energy of the merry-go-round:

W = Æke = !$I\omega$2 — 0 = !(!Mr2)($\Delta\theta/\Delta t$)2

= #(1640 kg)(8.20 m)2[(1 rev)(2¹ rad/rev)/(8.00 s)]2 = 1.70 ∞ 104 J.



54. We choose the reference level for gravitational potential energy at the bottom. The kinetic energy will be the translational energy of the center of mass and the rotational energy about the center of mass.

(a) Because there is no work done by friction while the cylinder is rolling, for the work-energy principle we have

W_{net} = Æke + Æpe;

0 = (!Mv2 + !$I\omega$2 — 0) + Mg(0 — d sin θ).

Because the cylinder is rolling, $v = R\omega$. The rotational inertia is ^MR2. Thus we get

!Mv2 + !(^MR2)(v/R2)2 = Mgd sin θ, which gives

v = ()gd sin θ)1/2, and ω = ()gd sin θ)1/2/R.

When we use the given data, we get

v = [)(9.80 m/s2)(10.0 m) sin 30°]1/2 = 8.37 m/s, and

$\omega = v/R$ = (8.37 m/s)/(0.200 m) = 41.8 rad/s.

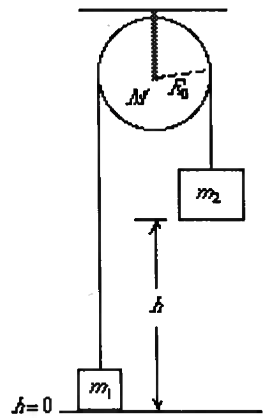
(b) For the ratio of kinetic energies we have

ke_{trans}/ke_{rot} = !Mv2/!$I\omega$2

= Mv2/(^MR2)(v/R2)2 = 2.50.

(c) None of the answers depends on the mass; the rotational speed depends on the radius.

55. For the system of the two blocks and pulley, no work will be



done by nonconservative forces. The rope ensures that each block has the same speed v and the angular speed of the pulley is $\omega = v/R_0$. We choose the reference level for gravitational potential energy at the floor.

The rotational inertia of the pulley is $I = !MR_0^2$.

For the work-energy principle we have

$W_{net} = Æke + Æpe$;

$0 = [(!m_1v^2 + !m_2v^2 + !I\omega^2) — 0] + m_1g(h — 0) + m_2g(0 — h)$;

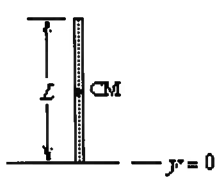
$!m_1v^2 + !m_2v^2 + !(!MR_0^2)(v/R_0)^2 = (m_2 — m_1)gh$;

$![m_1 + m_2 + !M]v^2 = (m_2 — m_1)gh$;

$![18.0 \text{ kg} + 26.5 \text{ kg} + !(7.50 \text{ kg})]v^2 =$

$(26.5 \text{ kg} — 18.0 \text{ kg})(9.80 \text{ m/s}^2)(3.00 \text{ m})$, which gives

$v = 3.22$ m/s.



56. If the contact point does not move, no work is done by the friction force. With the reference level for potential energy at the ground, we use energy conservation to find the angular speed just before the pole hits the ground:

$ke_i + pe_i = ke_f + pe_f$;

$0 + Mg!L = !(@ML^2)\omega^2 + 0$, which gives $\omega = (3g/L)^{1/2}$.

Because the pole is rotating about the contact point, the speed of the upper end is

$v = \omega L = (3gL)^{1/2} =[3(9.80 \text{ m/s}^2)(3.30 \text{ m})]^{1/2} = 9.85$ m/s.

57. The angular momentum of rotation about the fixed end of the string is

$L = I\omega = mR^2\omega$

$= (0.210 \text{ kg})(1.10 \text{ m})^2(10.4 \text{ rad/s}) = 2.64 \text{ kg} \cdot \text{m}^2/\text{s}$.

58. (*a*) As the arms are raised some of the person's mass is farther from the axis of rotation, so the moment of inertia has increased. For the isolated system of platform and person, the angular momentum is conserved. As the moment of inertia increases, the angular velocity must decrease.

(*b*) If the mass and thus the moment of inertia of the platform can be neglected, for the conservation of angular momentum, we have

$L = I_1\omega_1 = I_2\omega_2$, or

$I_2/I_1 = \omega_1/\omega_2 = (1.30\ \text{rad/s})/(0.80\ \text{rad/s}) = 1.6$.

59. Because the diver in the air is an isolated system, for the conservation of angular momentum we have

$L = I_1\omega_1 = I_2\omega_2$, or $I_2/I_1 = \omega_1/\omega_2$;

$1/3.5 = \omega_1/(2\ \text{rev}/1.5\ \text{s})$, which gives $\omega_1 = 0.38$ rev/s.

60. Because the skater is an isolated system, for the conservation of angular momentum we have

$L = I_1\omega_1 = I_2\omega_2$;

$(4.6\ \text{kg}\cdot\text{m}^2)(1.0\ \text{rev}/2.0\ \text{s}) = I_2(3.0\ \text{rev/s})$, which gives $I_2 = 0.77\ \text{kg}\cdot\text{m}^2$.

She accomplishes this by pulling her arms closer to her body.

61. If we approximate the hurricane as a solid cylinder, we have

$M = \rho(¹R^2H) = (1.3\ \text{kg/m}^3)¹(100 ∞ 10^3\ \text{m})^2(4.0 ∞ 10^3\ \text{m}) = 1.63 ∞ 10^{14}$ kg;

$I = !MR^2 = !(1.63 ∞ 10^{14}\ \text{kg})(100 ∞ 10^3\ \text{m})^2 = 8.15 ∞ 10^{23}\ \text{kg}\cdot\text{m}^2$.

The winds of a hurricane are obviously not uniform; they are generally higher near the eye. If we assume the highest winds are at half the radius, for the average angular speed we have

$\omega = v/!R = [(120\ \text{km/h})/(3.6\ \text{ks/h})]/!(100 ∞ 10^3\ \text{m}) = 6.67 ∞ 10^{-4}$ rad/s.

(*a*) For the kinetic energy we have

$\text{ke} = !I\omega^2 = !(8.15 ∞ 10^{23}\ \text{kg}\cdot\text{m}^2)(6.67 ∞ 10^{-4}\ \text{rad/s})^2$ Å $2 ∞ 10^{17}$ J.

(*b*) For the angular momentum we have

$L = I\omega = (8.15 ∞ 10^{23}\ \text{kg}\cdot\text{m}^2)(6.67 ∞ 10^{-4}\ \text{rad/s})$ Å $5 ∞ 10^{20}\ \text{kg}\cdot\text{m}^2/\text{s}$.

62. (*a*) We approximate the mass distribution as a solid cylinder. The angular momentum is

$L = I\omega = !mR^2\omega = !(55\ \text{kg})(0.15\ \text{m})^2[(3.5\ \text{rev/s})(2¹\ \text{rad/rev})] = 14\ \text{kg}\cdot\text{m}^2/\text{s}$.

(*b*) If the arms do not move, the moment of inertia will not change. We find the torque from the change in angular momentum:

$\tau = \Delta L/Æt = (0 — 14\ kg \cdot m2/s)/(5.0\ s) = — 2.7\ m \cdot N.$

63. (*a*) The Earth rotates one revolution in one day, so we have

$\omega_{rotation} = \Delta\theta/\Delta t$

$= (2^1\ rad)/(1\ day)(24\ h/day)(3600\ s/h) = 7.27 \infty 10—5\ rad/s.$

If we assume the Earth is a uniform sphere, the angular momentum is

$L_{rotation} = I_{rotation}\omega_{rotation} = (^\wedge Mr2)\omega_{rotation}$

$= (^\wedge)(6.0 \infty 1024\ kg)(6.4 \infty 106\ m)2(7.27 \infty 10—5\ rad/s) = 7.1 \infty 1033\ kg \cdot m2/s.$

(*b*) The Earth moves one revolution around the Sun in one year, so we have

$\omega_{orbit} = \Delta\theta/\Delta t$

$= (2^1\ rad)/(1\ yr)(3.16 \infty 107\ s/yr) = 1.99 \infty 10—7\ rad/s.$

The angular momentum is

$L_{revolution} = I_{revolution}\omega_{revolution} = (MR2)\omega_{revolution}$

$= (6.0 \infty 1024\ kg)(1.5 \infty 1011\ m)2(1.99 \infty 10—7\ rad/s) = 2.7 \infty 1040\ kg \cdot m2/s.$

64. If there are no external torques, angular momentum will be conserved:

$L = I_1\omega + I_2(0) = (I_1 + I_2)\omega_{final}$, or

$I\omega = (I + I)\omega_{final}$, which gives $\omega_{final} = \omega/2$.

65. If there are no external torques, angular momentum will be conserved:

$L = I_{disk}\omega_1 + I_{rod}(0) = (I_{disk} + I_{rod})\omega_2$;

$(Mr2/2)\omega_1 = [(Mr2/2) + (ML2/12)]\omega_2 = \{(Mr2/2) + [M(2r)2/12]\}\,\omega_2$, which gives

$\omega_2 = (3/5)\omega_1 = (3/5)(7.0\ rev/s) = 4.2\ rev/s.$

66. (*a*) By walking to the edge, the moment of inertia of the person changes. Because the system of person and platform is isolated, angular momentum will be conserved:

$L = (I_{platform} + I_{person1})\omega_1 = (I_{platform} + I_{person2})\omega_2$;

$[1000\ kg \cdot m2 + (75\ kg)(0)2](2.0\ rad/s) = [1000\ kg \cdot m2 + (75\ kg)(3.0\ m)2]\omega_2$, which gives

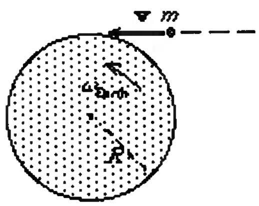
$\omega_2 = 1.2\ rad/s.$

(*b*) For the kinetic energies, we have

$ke_1 = !(I_{platform} + I_{person1})\omega_1^2 = !(1000\ kg \cdot m^2 + 0)(2.0\ rad/s)^2 = 2.0 \infty 10^3\ J;$

$ke_2 = !(I_{platform} + I_{person2})\omega_2^2 = ![1000\ kg \cdot m^2 + (75\ kg)(3.0\ m)^2](1.2\ rad/s)^2 = 1.2 \infty 10^3\ J.$

Thus there is a loss of $8.0 \infty 10^2$ J, a decrease of 40%.



67. The initial angular speed of the asteroid about the center of the Earth is

$\omega_a = v_a/R = (30 \infty 10^3\ m/s)/(6.4 \infty 10^6\ m) = 4.7 \infty 10^{—3}\ rad/s.$

The initial angular speed of the Earth is

$\omega_E = (2^1\ rad)/(1\ day)(24\ h/day)(3600\ s/h) = 7.27 \infty 10^{—5}\ rad/s.$

For the system of asteroid and Earth, angular momentum is conserved:

$I_{asteroid}\omega_a + I_{Earth}\omega_E = (I_{asteroid} + I_{Earth})\omega$ Å $I_{Earth}\omega$,

because the mass of the Earth is much greater than the mass of the

asteroid. This gives

$\omega — \omega_E$ Å $(I_{asteroid}/I_{Earth})\omega_a$.

For the fractional change, we have

$(\omega — \omega_E)/\omega_E$ Å $(I_{asteroid}/I_{Earth})(\omega_a/\omega_E) = (m_aR^2)/(\hat{}M_ER^2)](\omega_a/\omega_E)$

$= [(1.0 \infty 10^5\ kg)/\hat{}(6.0 \infty 10^{24}\ kg)][(4.7 \infty 10^{—3}\ rad/s)/(7.27 \infty 10^{—5}\ rad/s)] = 3 \infty 10^{—18}.$

68. When the people step onto the merry-go-round, they have no initial angular momentum. For the system of merry-go-round and people, angular momentum is conserved:

$I_{merry\text{-}go\text{-}round}\omega_0 + I_{people}\omega_i = (I_{merry\text{-}go\text{-}round} + I_{people})\omega$;

$I_{merry\text{-}go\text{-}round}\omega_0 + 4mR^2(0) = (I_{merry\text{-}go\text{-}round} + 4mR^2)\omega$;

$(1000\ kg \cdot m^2)(0.80\ rad/s) = [(1000\ kg \cdot m^2) + 4(65\ kg)(2.1\ m)^2]\omega$, which gives $\omega = 0.48$ rad/s.

If the people jump off in a radial direction with respect to the merry-go-round, they have the tangential velocity of the merry-go-round: $v = R\omega_0$. For the system of merry-go-round and people, angular momentum is conserved:

$(I_{merry\text{-}go\text{-}round} + I_{people})\omega_0 = I_{merry\text{-}go\text{-}round}\omega + I_{people}\omega_0$, which gives

$\omega = \omega_0$. The angular speed of the merry-go-round does not change.

Note that the angular momentum of the people will change when contact is made with the ground.

69. We assume that the lost mass does not carry away any angular momentum. For the Sun, angular momentum is conserved:

$I_0\omega_0 = I\omega$;

$^\wedge M_1R_{12}\omega_0 = {}^\wedge M_2R_{22}\omega$; or

$\omega = (R_1/R_2)_2(M_1/M_2)\omega_0 = (1/0.01)_2(1/0.5)(2^1 \text{ rad})/(30 \text{ days})(24 \text{ h/day})(3600 \text{ s/h})$

$= 4.8 \infty 10_{—2}$ rad/s.

The new period is 130 s.

For the ratio of kinetic energies we have

$\text{ke}_2/\text{ke}_1 = {!}I\omega_2/{!}I_0\omega_{02}$

$= {!}({}^\wedge M_2R_{22})[(R_1/R_2)_2(M_1/M_2)]_2\omega_{02}/{!}({}^\wedge M_1R_{12})\omega_{02}$

$= (R_1/R_2)_2(M_1/M_2) = (1/0.01)_2(1/0.5) = 2.0 \infty 10_4$, or $\text{ke}_2 = 2.0 \infty 10_4\, \text{ke}_1$.

70. We choose the direction the person walks for the positive rotation. The speed of the person with respect to the turntable is v. If the edge of the turntable acquires a speed v_t with respect to the ground, the speed of the person will be $v_t + v$. Because all speeds are the same distance from the axis, if we divide by R, we get

$\omega_p = \omega_t + (v/R)$.

Using the speeds with respect to the ground, from the conservation of angular momentum of the system of turntable and person, we have

$L = 0 = I_t\omega_t + I_p\omega_p = I_t\omega_t + m_pR_2[\omega_t + (v/R)]$;

$(1000 \text{ kg} \cdot \text{m}_2)\omega_t + (55 \text{ kg})(3.25 \text{ m})_2\{\omega_t + [(3.8 \text{ m/s})/(3.25 \text{ m})]\} = 0$, which gives

$\omega_t = —0.30$ rad/s.

The negative sign indicates a motion opposite to that of the person.

71. Initially there is no angular momentum about the vertical axis. Because there are no torques about this vertical axis for the system of platform and wheel, the angular momentum about the vertical axis is zero and conserved. We choose up for the positive direction.

(*a*) From the conservation of angular momentum about the vertical axis, we have

$L = 0 = I_P\omega_P + I_W\omega_W$, which gives $\omega_P = —(I_W/I_P)\omega_W$ (down).

(*b*) From the conservation of angular momentum about the vertical axis, we have

$L = 0 = I_P\omega_P + I_W\omega_W \cos 60°$, which gives $\omega_P = —(I_W/2I_P)\omega_W$ (down).

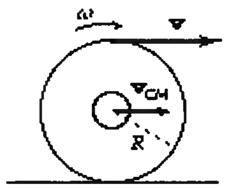
(*c*) From the conservation of angular momentum about the vertical axis, we have

$L = 0 = I_P\omega_P + I_W(—\omega_W)$, which gives $\omega_P = (I_W/I_P)\omega_W$ (up).

(*d*) Because the total angular momentum is zero, when the wheel stops, the platform and person

must also stop.

Thus $\omega_P = 0$.



72. Because the spool is rolling, $v_{CM} = R\omega$. The velocity of the rope at the top of the spool, which is also the velocity of the person, is

$v = R\omega + v_{CM} = 2R\omega = 2v_{CM}$.

Thus in the time it takes for the person to walk a distance L, the CM will move a distance $L/2$. Therefore, the length of rope that unwinds is

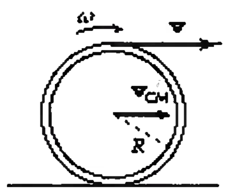
$L_{rope} = L - (L/2) = L/2$.

The CM will move a distance $L/2$.

73. For the same side of the Moon to always face the Earth, the angular velocity of the orbital motion and the angular velocity of the spinning motion must be the same. We use r for the radius of the Moon and R for the distance from the Earth to the Moon. For the ratio of angular momenta, we have

$L_{spin}/L_{orbital} = $ ^$Mr^2\omega/MR^2\omega$

$=$ ^$(r/R)^2 =$ ^$[(1.74 \infty 10^6 \text{ m})/(3.84 \infty 10^8 \text{ m})]^2 = 8.21 \infty 10^{-6}$.



74. After 3.0 s the velocity of the CM will be

$v_{CM} = 0 + a_{CM}t = (1.00 \text{ m/s}^2)(3.0 \text{ s}) = 3.0 \text{ m/s}$.

Because the wheel is rolling, $v_{CM} = R\omega$. The velocity at the top of the wheel is

$v = R\omega + v_{CM} = 2R\omega = 2v_{CM} = 2(3.0 \text{ m/s}) = 6.0 \text{ m/s}$.

75. (*a*) The yo-yo is considered as three cylinders, with a total mass of

$M = 2M_{disk} + M_{hub} = 2(0.050 \text{ kg}) + 0.0050 \text{ kg} = 0.105 \text{ kg}$,

and a moment of inertia of the yo-yo about its axis of

$I = 2(!M_{disk}R_{disk}^2) + !M_{hub}R_{hub}^2$

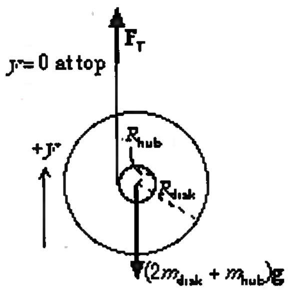
$= (0.050 \text{ kg})[!(0.075 \text{ m})]^2 + !(0.0050 \text{ kg})[!(0.010 \text{ m})]^2$

$= 7.04 \infty 10^{-5} \text{ kg} \cdot \text{m}^2$.

Because the yo-yo is rolling about a point on the rim of the hub,

$v_{CM} = R_{hub}\omega$.

The kinetic energy of the yo-yo is the translational kinetic energy of the CM and the rotational kinetic energy about the CM. Because the top of the string does not move, the tension in the string does no work. Thus energy is conserved:



$ke_i + pe_i = ke_f + pe_f$;

$0 + 0 = !Mv_{CM}^2 + !I\omega^2 + Mg(—L)$;

$!Mv_{CM}^2 + !I(v_{CM}/R_{hub})^2 = MgL$;

$!\{0.105\text{ kg} + [(7.04 \infty 10^{—5}\text{ kg}\cdot\text{m}^2)/(0.0050\text{ m})^2]\}v_{CM}^2 = (0.105\text{ kg})(9.80\text{ m/s}^2)(1.0\text{ m})$,

which gives $v_{CM} = 0.84$ m/s.

(*b*) For the fraction of the kinetic energy that is rotational, we have

$ke_{rot}/(ke_{trans} + ke_{rot}) = !I\omega^2 /(!Mv_{CM}^2 + !I\omega^2)$

$= I\omega^2/[M(R_{hub}\omega)^2 + I\omega^2] = 1/[(MR_{hub}^2/I) + 1]$

$= 1/\{[(0.105\text{ kg})(0.0050\text{ m})^2/(7.04 \infty 10^{—5}\text{ kg}\cdot\text{m}^2)] + 1\} = 0.964$.

76. (*a*) If we let *d* represent the spacing of the teeth, which is the same on both sprockets, we can relate the number of teeth to the radius for each wheel:

$N_Fd = 2^1R_F$, and $N_Rd = 2^1R_R$, which gives $N_F/N_R = R_F/R_R$.

The linear speed of the chain is the tangential speed for each socket:

$v = R_F\omega_F = R_R\omega_R$.

Thus we have

$\omega_R/\omega_F = R_F/R_R = N_F/N_R$.

(*b*) For the given data we have

$\omega_R/\omega_F = 52/13 = 4.0$.

(*c*) For the given data we have

$\omega_R/\omega_F = 42/28 = 1.5$.

77. We assume that the lost mass does not carry away any angular momentum. For the star, angular momentum is conserved:

$I_0\omega_0 = I\omega$;

$^M_1R_1^2\omega_0 = {}^M_2R_2^2\omega$; or

$\omega = (R_1/R_2)^2(M_1/M_2)\omega_0$

$= (6.96 \infty 10^6\text{ km}/10\text{ km})^2(1/0.25)[(1.0\text{ rev})/(10\text{ days})] = 2.0 \infty 10^9$ rev/day.

78. We convert the speed: (90 km/h)/(3.6 ks/h) = 25 m/s.

(*a*) We assume that the linear kinetic energy that the automobile acquires during each acceleration is not regained when the automobile slows down. For the work-energy principle we have

W_{net} = Æke + Æpe;

— $F_{fr}D$ = [20(!Mv^2) — $ke_{flywheel}$] + 0, or

$ke_{flywheel}$ = (20)!(1400 kg)(25 m/s)2 + (500 N)(300 ∞ 103 m) = 1.6 ∞ 108 J.

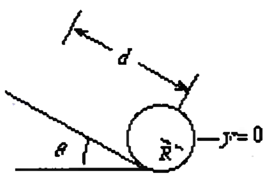
(*b*) We find the angular velocity of the flywheel from

$ke_{flywheel}$ = !$I\omega^2$ = !(!mR^2)ω^2;

1.6 ∞ 108 J = #(240 kg)(0.75 m)2ω^2, which gives ω = 2.2 ∞ 103 rad/s.

(*c*) We find the time from

t = $ke_{flywheel}$ /P = (1.6 ∞ 108 J)/(150 hp)(746 W/hp) = 1.43 ∞ 103 s = 24 min.



79. (*a*) We choose the reference level for gravitational potential energy at the initial position at the bottom of the incline. The kinetic energy will be the translational energy of the center of mass and the rotational energy about the center of mass. Because there is no work done by friction while the cylinder is rolling, for the work-energy principle we have

W_{net} = Æke + Æpe;

0 = [0 — (!Mv^2 + !$I\omega^2$)] + Mg(d sin θ — 0).

Because the cylinder is rolling, $v = R\omega$. For a hoop the moment of inertia is MR^2. Thus we get

!Mv^2 + !(MR^2)(v^2/R^2) = Mv^2 = Mgd sin θ;

(4.3 m/s)2 = (9.80 m/s2)d sin 15°, which gives d = 7.3 m.

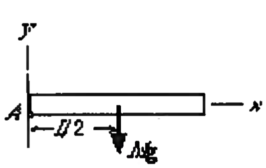
(*b*) We find the time to go up the incline from the linear motion (which has constant acceleration):

d = !(v + 0)t;

7.3 m = !(4.3 m/s)t, which gives t = 3.4 s.

Because there are no losses to friction, the time to go up the incline will be the same as the time to return. The total time will be

$T = 2t$ = 6.8 s.



80. (*a*) For the angular acceleration of the rod about the pivot, we have

$\Sigma\tau = I\alpha$;

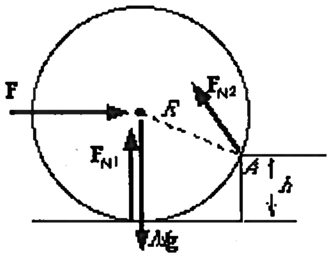
$MgL/2$ = @$ML^2\alpha$, which gives $\alpha = 3g/2L$.

(b) The tangential acceleration of the end of the rod is

$a_{tan} = \alpha L = (3g/2L)(L) = 3g/2.$

Note that there is no radial acceleration of the end of the rod at the moment of release because there is no tangential speed then.

81. The cylinder will roll about the contact point A.



We write $\Sigma\tau = I\alpha$ about the point A:

$F(R - h) + F_{N1}[R^2 - (R - h)^2]^{1/2} - Mg[R^2 - (R - h)^2]^{1/2} = I_A\alpha.$

When the cylinder does roll over the curb, contact with the ground is lost and $F_{N1} = 0$. Thus we get

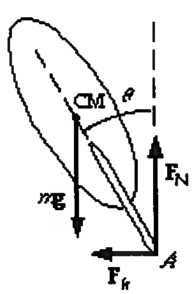
$F = \{I_A\alpha + Mg[R^2 - (R - h)^2]^{1/2}\}/(R - h)$

$= [I_A\alpha/(R - h)] + [Mg(2Rh - h^2)^{1/2}/(R - h)].$

The minimum force occurs when $\alpha = 0$:

$F_{min} = Mg[h(2R - h)]^{1/2}/(R - h).$

82. (a) If we consider an axis through the CM parallel to the velocity vector



(that is, parallel to the ground), there is no angular acceleration about this axis. If d is the distance from the CM to the contact point on the ground, we have

$\Sigma\tau = I\alpha;$

$F_N d \sin\theta - F_{fr} d \cos\theta = 0$, which gives $\tan\theta = F_{fr}/F_N$.

(b) The friction force is producing the necessary radial acceleration for the turn:

$F_{fr} = F_N \tan\theta = mg \tan\theta = mv^2/r$, or

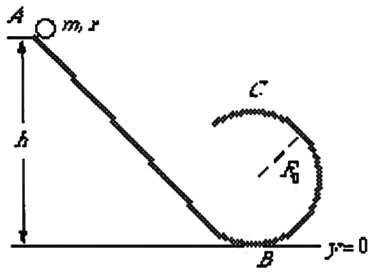
$\tan\theta = v^2/gr = (4.2 \text{ m/s})^2/(9.80 \text{ m/s}^2)(6.4 \text{ m}) = 0.281$, so $\theta = 16°$.

(c) From

$F_{fr} = mv^2/r,$

we see that the minimum turning radius requires the maximum static friction force:

$\mu_s mg = mv^2/r_{min}$, or $r_{min} = v^2/\mu_s g = (4.2 \text{ m/s})^2/(0.70)(9.80 \text{ m/s}^2) = 2.6$ m.



83. At the top of the loop, if the marble stays on the track, the normal force and the weight provide the radial acceleration:

$F_N + mg = mv2/R_0$.

The minimum value of the normal force is zero, so we find the minimum speed at the top from

$mg = mv_{\min}2/R_0$, or $v_{\min}2 = gR_0$.

Because the marble is rolling, the corresponding angular velocity at the top is $\omega_{\min} = v_{\min}/r$, so the minimum kinetic energy at the top is

$\text{ke}_{\min} = !mv_{\min}2 + !I\omega_{\min}2$

$= !mv_{\min}2 + !(\hat{}mr2)(v_{\min}/r)2 = 7mv_{\min}2/10$

$= 7mgR_0/10$.

If there are no frictional losses, we use energy conservation from the release point to the highest point of the loop:

$\text{ke}_i + \text{pe}_i = \text{ke}_f + \text{pe}_f;$

$0 + mgh_{\min} = \text{ke}_{\min} + mg2R_0 = 7mgR_0/10 + 2mgR_0$, which gives $h_{\min} = 2.7R_0$.

84. If r is not much smaller than R_0, the CM of the marble moves around the loop in a circle with radius $R_0 - r$. At the minimum speed at the top of the loop, the weight provides the radial acceleration:

$mg = mv_{\min}2/(R_0 - r)$, or $v_{\min}2 = g(R_0 - r)$.

The corresponding angular velocity at the top is $\omega_{\min} = v_{\min}/r$, so the minimum kinetic energy is

$\text{ke}_{\min} = !mv_{\min}2 + !I\omega_{\min}2$

$= !mv_{\min}2 + !(\hat{}mr2)(v_{\min}/r)2 = 7mv_{\min}2/10 = 7mg(R_0 - r)/10$.

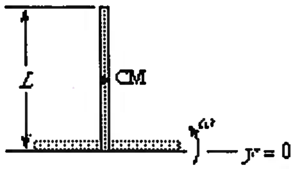
The distance h is to the bottom of the marble. We use energy conservation from the release point to the highest point of the loop:

$\text{ke}_i + \text{pe}_i = \text{ke}_f + \text{pe}_f;$

$0 + mg(h_{\min} + r) = \text{ke}_{\min} + mg(2R_0 - r) = 7mg(R_0 - r)/10 + mg(2R_0 - r)$,

which gives $h_{\min} = 2.7(R_0 - r)$.

85. Because there is no friction, the CM must fall straight down. The



vertical velocity of the right end of the stick must always be zero. If ω is the angular velocity of the stick just before it hits the table, velocity of the right end with respect to the CM will be $\omega(L/2)$ up.

Thus we have

$\omega(L/2) - v_{CM} = 0$, or $\omega = 2v_{CM}/L$.

The kinetic energy will be the translational energy of the center of mass and the rotational energy about the center of mass. With the reference level for potential energy at the ground, we use energy conservation to find the speed of the CM just before the stick hits the ground:

$ke_i + pe_i = ke_f + pe_f$;

$0 + Mg!L = !Mv_{CM}^2 + !(ML^2/12)\omega^2 + 0$;

$Mg!L = !Mv_{CM}^2 + !(ML^2/12)(2v_{CM}/L)^2 = !(Mv_{CM}^2/3)$, which gives $v_{CM} = (3gL/4)^{1/2}$.