9.17: From Eq. (0.12), with \( \omega_z = 0 \), the number of revolutions is proportional to the square of the initial angular velocity, so tripling the initial angular velocity increases the number of revolutions by 9, to 9.0 rev.

9.31: a) For a given radius and mass, the force is proportional to the square of the angular velocity; \( \left( \frac{640 \text{ rev/min}}{123 \text{ rev/min}} \right)^2 = 2.29 \) (note that conversion to rad/s is not necessary for this part). b) For a given radius, the tangential speed is proportional to the angular velocity; \( \frac{640}{423} = 1.51 \) (again conversion of the units of angular speed is not necessary).

c) \( 640 \text{ rev/min} \left( \frac{\pi}{30} \frac{\text{rad/s}}{\text{rev/min}} \right) \left( \frac{0.470 \text{ m}}{2} \right) = 15.75 \text{ m/s}, \) or 15.7 m/s to three figures, and \( a_{\text{rad}} = \frac{v^2}{r} = \frac{(15.75 \text{ m/s})^2}{(0.470 \text{ m})/2} = 1.06 \times 10^3 \text{ m/s}^2 = 108g. \)

9.53: \( \frac{2}{3} MR^2 = \frac{2}{5} MR^2 + Md^2 \), so \( d^2 = \frac{4}{15} R^2 \), and the axis comes nearest to the center of the sphere at a distance \( d = (2/\sqrt{15}) R = (0.516)R. \)

10.18:
\[
\alpha = \frac{\tau}{I} = \frac{F l}{\frac{1}{3} M l^2} = \frac{3F}{Ml}.
\]
9.69: a) Expressing angular frequencies in units of revolutions per minute may be accommodated by changing the units of the dynamic quantities; specifically,

\[
\omega_2 = \sqrt{\omega_1^2 + \frac{2W}{I}}
\]

\[
= \sqrt{(300 \text{ rev/min})^2 + \left(\frac{2(-4000 \text{ J})}{16.0 \text{ kg} \cdot \text{m}^2}\right) / \left(\frac{\pi}{30} \frac{\text{rad/s}}{\text{rev/min}}\right)^2}
\]

= 211 \text{ rev/min}.

b) At the initial speed, the 4000 J will be recovered; if this is to be done in 5.00 s, the power must be \( \frac{4000 \text{ J}}{5.00 \text{ s}} = 800 \text{ W} \).

9.70: a) The angular acceleration will be zero when the speed is a maximum, which is at the bottom of the circle. The speed, from energy considerations, is

\[
v = \sqrt{2gh} = \sqrt{2gR(1 - \cos \beta)}
\]

where \( \beta \) is the angle from the vertical at release, and

\[
\omega = \frac{v}{R} = \sqrt{\frac{2g}{R}(1 - \cos \beta)} = \sqrt{\frac{2(9.80 \text{ m/s}^2)}{(2.50 \text{ m})}(1 - \cos 36.9^\circ)} = 1.25 \text{ rad/s}.
\]

b) \( \alpha \) will again be 0 when the meatball again passes through the lowest point.

c) \( a_{rad} \) is directed toward the center, and

\[
a_{rad} = \omega^2 R, \quad a_{rad} = (1.25 \text{ rad/s})^2(2.50 \text{ m}) = 3.93 \text{ m/s}^2.
\]

d) \( a_{rad} = \omega^2 R = (2g/R)(1 - \cos \beta)R = (2g)(1 - \cos \beta) \), independent of \( R \).
\[ I = I_{\text{wood}} + I_{\text{lead}} \]
\[ = \frac{2}{5} m_w R^2 + \frac{2}{3} m_L R^2 \]
\[ m_w = \rho_w V_w = \rho_w \frac{4}{3} \pi R^3 \]
\[ m_L = \sigma_L A_L = \sigma_L 4\pi R^2 \]
\[ I = \frac{2}{5} \left( \rho_w \frac{4}{3} \pi R^3 \right) R^2 + \frac{2}{3} \left( \sigma_L 4\pi R^2 \right) R^2 \]
\[ = \frac{8}{3} \pi R^4 \left( \frac{\rho_w R}{5} + \sigma_L \right) \]
\[ = \frac{8\pi}{3} (0.20 \text{ m})^4 \left[ \frac{(800 \text{ kg/m}^3)(0.20 \text{ m})}{5} + 20 \text{ kg/m}^2 \right] \]
\[ = 0.70 \text{ kgm}^2 \]
10.22: a) The acceleration down the slope is \( a = g \sin \theta - \frac{f}{M} \), the torque about the center of the shell is
\[
\tau = Rf = I \alpha = I \frac{a}{R} = \frac{2}{3} MR^2 \frac{a}{R} = \frac{2}{3} MRa,
\]
so \( \frac{f}{M} = \frac{2}{3} a \). Solving these relations for \( a \) and \( f \) simultaneously gives \( \frac{5}{3} a = g \sin \theta \), or
\[
a = \frac{3}{5} g \sin \theta = \frac{3}{5} (9.80 \text{ m/s}^2) \sin 38.0^\circ = 3.62 \text{ m/s}^2,
\]
\[
f = \frac{2}{3} Ma = \frac{2}{3} (2.00 \text{ kg})(3.62 \text{ m/s}^2) = 4.83 \text{ N}.
\]
The normal force is \( Mg \cos \theta \), and since \( f \leq \mu_s n \),
\[
\mu_s \geq \frac{f}{n} = \frac{\frac{2}{3} Ma}{Mg \cos \theta} = \frac{2}{3} \frac{a}{g \cos \theta} = \frac{2}{3} \frac{3}{5} g \sin \theta = \frac{2}{5} \tan \theta = 0.313.
\]
b) \( a = 3.62 \text{ m/s}^2 \) since it does not depend on the mass. The frictional force, however, is twice as large, 9.65 N, since it does depend on the mass. The minimum value of \( \mu_s \) also does not change.
10.29:  

a) \[ \tau = I \alpha = I \frac{\Delta \omega}{\Delta t} \]

\[ = \frac{((1/2)(1.50 \text{ kg})(0.100 \text{ m})^2)(1200 \text{ rev/min}) \left( \frac{\pi}{30} \frac{\text{ rad/s}}{\text{ rev/min}} \right)}{2.5 \text{ s}} \]

\[ = 0.377 \text{ N.m.} \]

b) \[ \omega_{\text{ave}} \Delta t = \frac{(600 \text{ rev/min})(2.5 \text{ s})}{60 \text{ s/min}} = 25.0 \text{ rev} = 157 \text{ rad.} \]

c) \[ \tau \Delta \theta = 59.2 \text{ J.} \]

d) \[ K = \frac{1}{2} I \omega^2 \]

\[ = \frac{1}{2} \left( (1/2)(1.5 \text{ kg})(0.100 \text{ m})^2 \right) \left( 1200 \text{ rev/min} \left( \frac{\pi}{30} \frac{\text{ rad/s}}{\text{ rev/min}} \right) \right)^2 \]

\[ = 59.2 \text{ J,} \]

the same as in part (c).
10.36: For both parts, $L = I\omega$. Also, $\omega = v/r$, so $L = I(v/r)$.

   a) $L = (mr^2)(v/r) = mvr$
      
      \[ L = (5.97 \times 10^{24} \text{ kg})(2.98 \times 10^4 \text{ m/s})(1.50 \times 10^{11} \text{ m}) = 2.67 \times 10^{40} \text{ kg} \cdot \text{m}^2/\text{s} \]

   b) $I = (2/5 mr^2)(\omega)$
      
      \[ L = (2/5)(5.97 \times 10^{24} \text{ kg})(6.38 \times 10^6 \text{ m})^2(2\pi \text{ rad}/(24.0 \text{ hr} \times 3600 \text{ s/hr})) \]
      \[ = 7.07 \times 10^{33} \text{ kg} \cdot \text{m}^2/\text{s} \]

10.45: Apply conservation of angular momentum $\vec{L}$, with the axis at the nail. Let object $A$ be the bug and object $B$ be the bar.

   Initially, all objects are at rest and $L_1 = 0$.

   Just after the bug jumps, it has angular momentum in one direction of rotation and the bar is rotating with angular velocity $\omega_B$ in the opposite direction.

   \[ L_2 = m_A v_A r - I_B \omega_B \text{ where } r = 1.00 \text{ m and } I_B = \frac{1}{3} m_B r^2 \]
   
   \[ L_1 = L_2 \text{ gives } m_A v_A r = \frac{1}{3} m_B r^2 \omega_B \]
   
   \[ \omega_B = \frac{3m_A v_A}{m_B r} = 0.120 \text{ rad/s} \]
10.58: a) From geometric consideration, the lever arm and the sine of the angle between $\vec{F}$ and $\vec{r}$ are both maximum if the string is attached at the end of the rod. b) In terms of the distance $x$ where the string is attached, the magnitude of the torque is $F \cdot x h/\sqrt{x^2 + h^2}$. This function attains its maximum at the boundary, where $x = h$, so the string should be attached at the right end of the rod. c) As a function of $x$, $l$ and $h$, the torque has magnitude

$$\tau = F \frac{xh}{\sqrt{(x - l/2)^2 + h^2}}.$$

This form shows that there are two aspects to increasing the torque: maximizing the lever arm $l$ and maximizing $\sin \phi$. Differentiating with respect to $x$ and setting equal to zero gives $x_{\text{max}} = (l/2)(1 + (2h/l)^2)$. This will be a maximum if $2h > l$, in which case the string should be attached at the string unless $x = l$. In this case, the torque attains its maximum at the right end of the rod.
10.60: In Fig. (10.22) and Eq. (10.22), with the angle $\theta$ measured from the vertical, \( \sin \phi - \cos \theta \) in Eq. (10.2). The torque is then \( \tau = FR \cos \theta \).

\[ a) \quad W = \int_{0}^{\pi/2} FR \cos \theta \, d\theta = \frac{1}{2} R. \]

b) In Eq. (6.14), \( dl \) is the horizontal distance the point moves, and so \( W = F \int dl - FR \), the same as part (a). c) From \( K_2 - W - (MR^2/4)\omega^2 \), \( \omega = \sqrt{4F/MR} \). d) The torque, and hence the angular acceleration, is greatest when \( \theta = 0 \), at which point \( \alpha = (\tau/I) = 2F/MR \), and so the maximum tangential acceleration is \( 2F/M \). e) Using the value for \( \omega \) found in part (c), \( a_{\text{rad}} = \omega^2 R = 4F/M \).

10.71: a) Because there is no vertical motion, the tension is just the weight of the hoop:

\( T = Mg = (0.180 \text{ kg})(9.8 \text{ N/kg}) = 1.76 \text{ N} \)

b) Use \( \tau = I\alpha \) to find \( \alpha \). The torque is \( RT \), so \( \alpha = RT/I = RT/MR^2 = T/MR = Mg/MR \), so \( \alpha = g/R = (9.8 \text{ m/s}^2)/(0.08 \text{ m}) = 122.5 \text{ rad/s}^2 \)

c) \( a = R\alpha = 9.8 \text{ m/s}^2 \)

d) \( T \) would be unchanged because the mass \( M \) is the same, \( \alpha \) and \( a \) would be twice as great because \( I \) is now \( \frac{1}{2} MR^2 \).