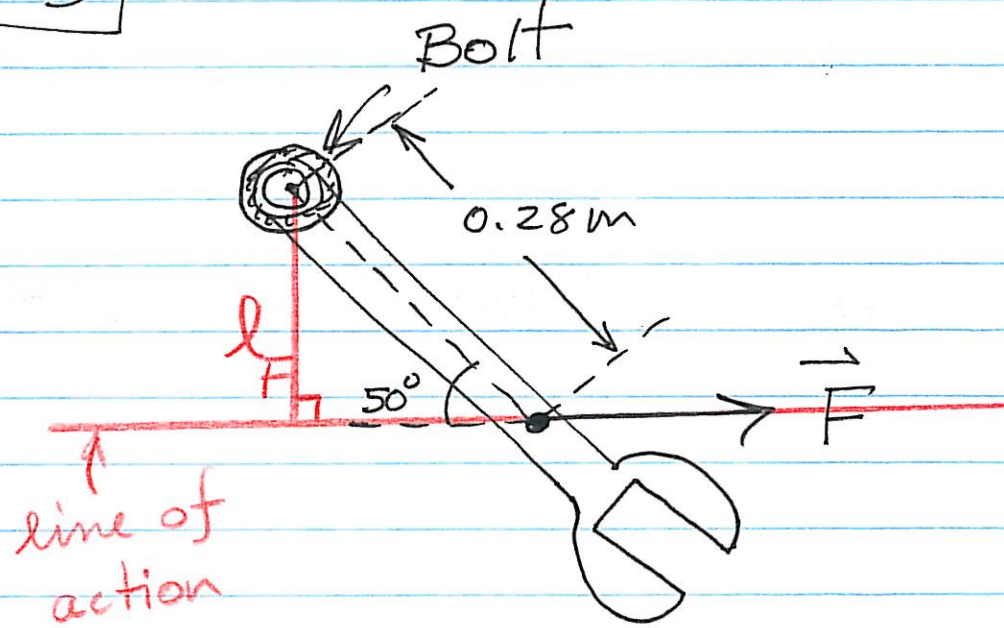
Chapter 9

$\boxed{9\text{-}3}$



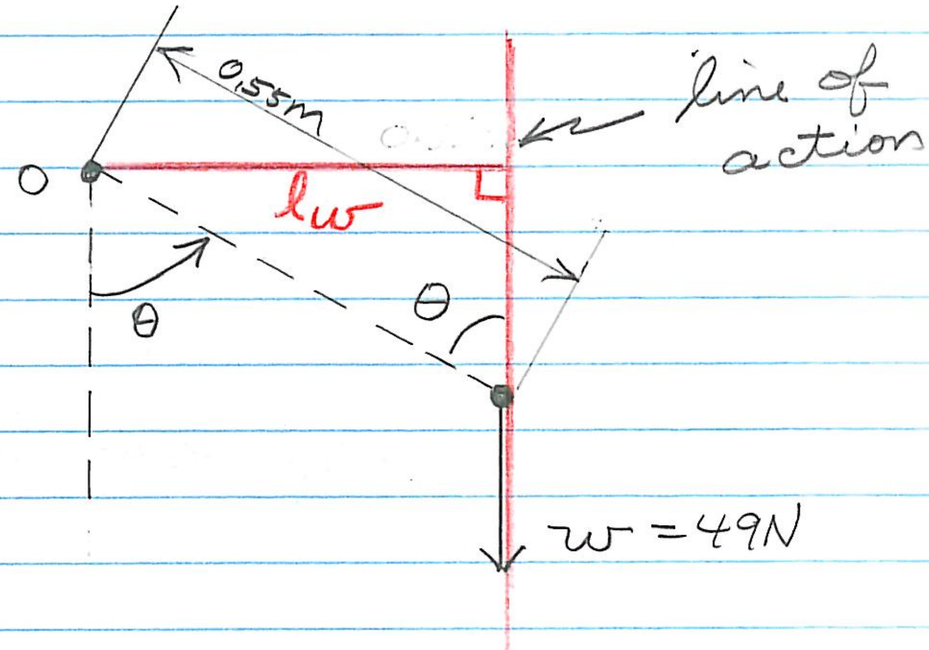
$$\tau_{bolt} = l_F F$$

$$l_F = 0.28 \sin 50^\circ = 0.21 m$$

$$0.21 F = 45 \text{ N} \cdot \text{m}$$

$$F = 210 \text{ N}$$

$\boxed{9.5}$



(a) $\tau_O = l_w w$

$l_w = 0.55 \sin\theta$

for $\theta = 90°$, $l_w = 0.55$

$\tau_O = 0.55 \times 49 = \underline{27 \text{ N·m}}$

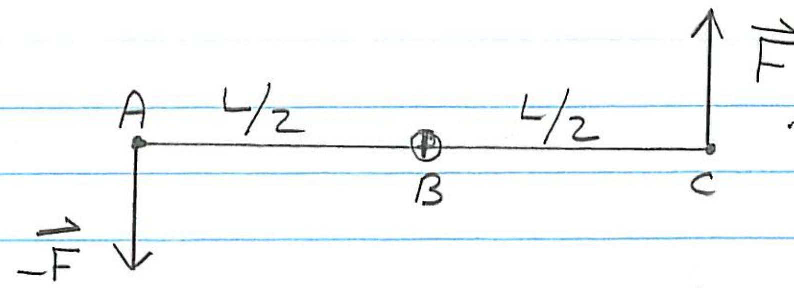
(b) $15 = l_w w = 0.55 \sin\theta \times 49$

$15 = 27 \sin\theta$

$\sin\theta = 0.56$

$\underline{\theta = 34°}$

$\boxed{9-9}$



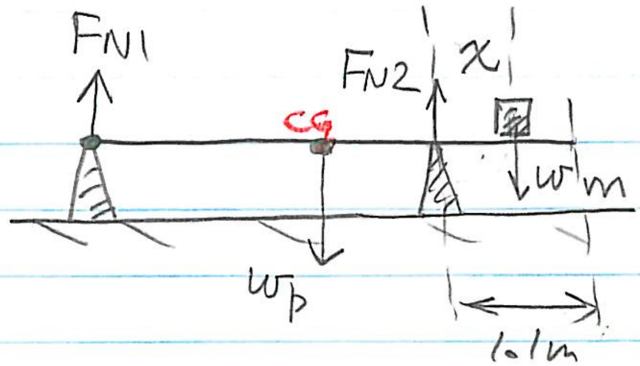
(a) $\tau_A = +F\,l_{F_A} = +FL$

(b) $\tau_B = +F\,L/2 + F\,L/2 = +FL$

(c) $\tau_C = +FL$

$\therefore \tau_A = \tau_B = \tau_C$

$\boxed{9\text{-}12}$



$W_p = 225N$
$L = 5m$
$W_m = 450N$

Forces: $F_{N1} + F_{N2} - W_p - W_m = 0$

Take torques about left support

Torques: $F_{N2}(3.9m) - W_p(2.5m) - W_m(3.9 + x) = 0$

when plank just begins to tip over
$F_{N1} = 0$

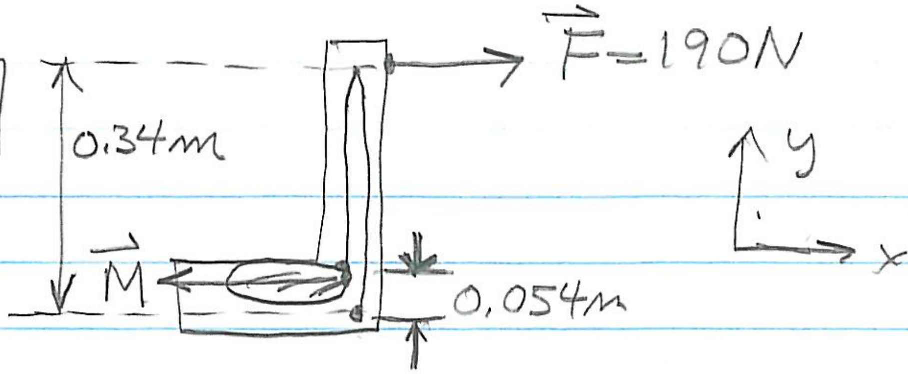
$F_{N2} = W_p + W_m = 675N$

$675(3.9) - 225(2.5) - 450(3.9 + x) = 0$
$2632.5 - 562.5 - 1755 - 450x = 0$

$315 = 450x$

$x = 0.7m$

$\boxed{9-15}$



$M l_M - F l_F = 0$ (about the elbow joint)

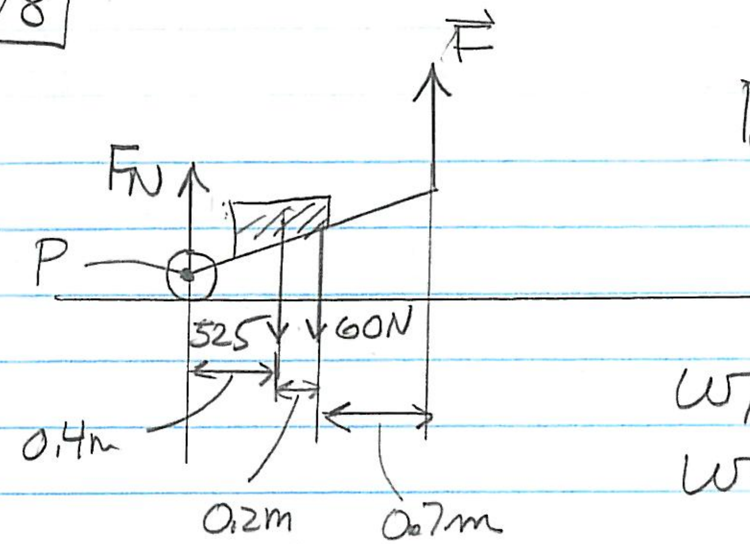
$M(0.054) - 190(0.34) = 0$

$$M = \frac{190(0.34)}{0.054}$$

$= 1196\ N \leftarrow$

Note that $\vec{F}$ and $\vec{M}$ are not the only horizontal forces involved here, but they are the forces that produce torques about the elbow joint.

9-18



Design 1

$W_1 = 525N$

$W_2 = 60N$

$$F_N + F - W_1 - W_2 = 0$$

$$F_N + F = 585\,N$$

$$\tau_p = F(1.3m) - W_1(0.4) - W_2(0.6) = 0$$

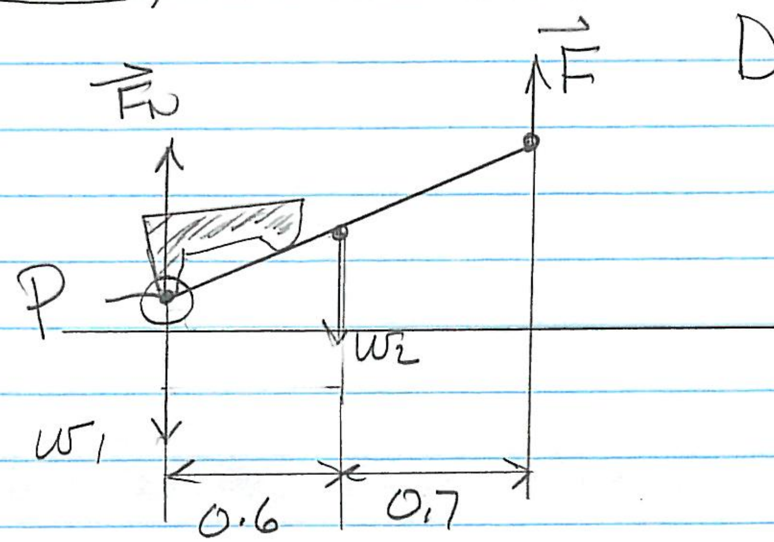
$$1.3F - 525(0.4) - 60(0.6) = 0$$

$$1.3F = 210 + 36 = 246$$

$$\underline{F = 189\,N}$$

9-18, continued

Design 2



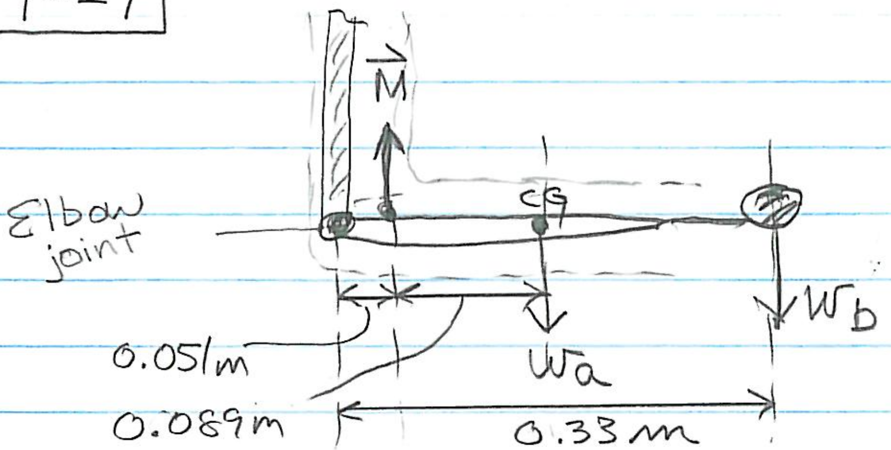
$$\tau_p = F(1.3) - w_2(0.6)$$

$$0 = 1.3F - 0.6(60)$$

$$1.3F = 36$$

$$\underline{F = 27.7\,N}$$

9-27



$W_a = 22\ N$

$W_b = 178N$

(a) Take torques about the elbow joint, then the force there produces no torque

$$0 = \sum \tau = M(0.051) - W_a(0.089 + 0.051) - W_b(0.33)$$

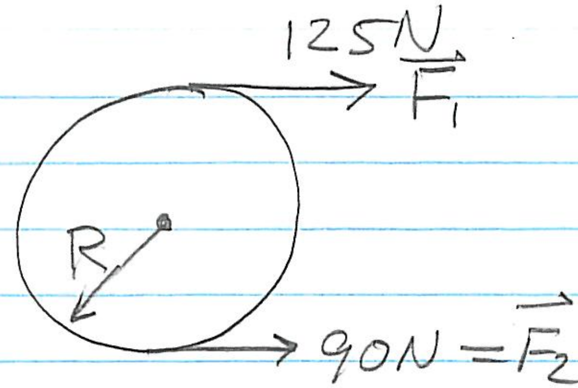
$$0 = 0.051M - 22(0.14) - 0.33(178)$$

$$0.051M = 3.08 + 58.7 = 61.82$$

$$M = 1212N$$

(b) $W_a + W_b = 200N$ which is much less than M, so the upper arm must exert $1212 - 200 = 1012\ N$ downward to ensure $\sum \vec{F} = 0$

$\boxed{9\text{–}32}$



(a) $\tau_{NET} = F_2 R - F_1 R$ (*)

$= (F_2 - F_1) = (90-125) \times 0.314\,m$

$= -11\ N \cdot m$

(b) $\tau_{NET} = I\alpha$

$I_{DISK} = \frac{1}{2} M R^2$ (TABLE 9-1)

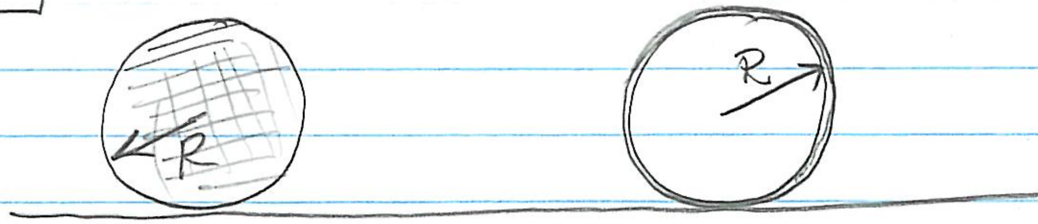
$= \frac{1}{2} \times 24.3\,(0.314)^2 = 1.2\ kg \cdot m^2$

$\alpha = \dfrac{-11}{1.2} = -9.2\ rad/s^2$

Clockwise

* We take ccw torques as +

$\boxed{9\text{-}35}$



$$I_{disk} = \frac{1}{2}MR^2, \quad I_{hoop} = MR^2$$

$$I_{disk} = \frac{1}{2}(4\,kg)(0.35\,m)^2 = 0.25\ kg\cdot m^2$$

$$I_{hoop} = 0.49\ kg\cdot m^2$$

$$\theta = \frac{1}{2}\alpha t^2$$

$$\alpha = \frac{2\theta}{t^2} = \frac{2 \times 13\,rad}{(8)^2} = 0.41\ RAD/s^2$$

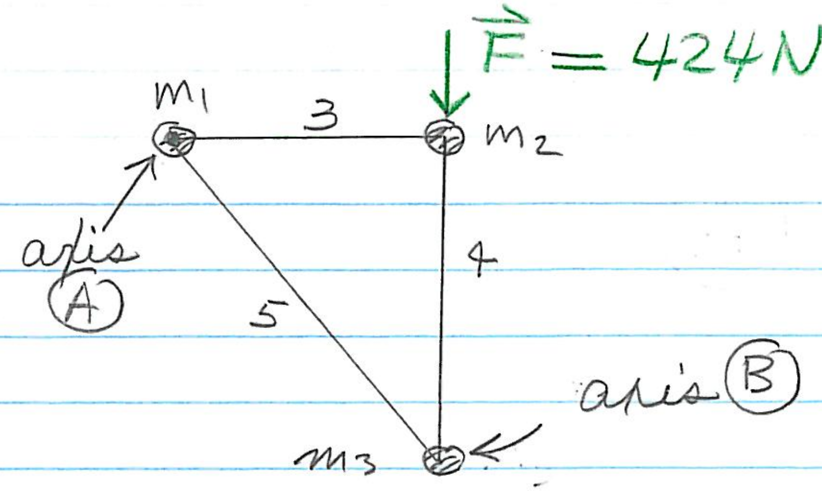
$$\tau = I\alpha$$

$$\tau_{disk} = 0.25 \times 0.41 = 0.1\ N\cdot m$$

$$\tau_{hoop} = 0.49 \times 0.41 = 0.2\ N\cdot m$$

$\therefore$ it takes twice as much torque to produce the same angular acceleration of the hoop compared to the solid disk. The hoop has all the mass further from the axis of rotation than the disk.

9-43



$m_1 =$ 9 kg
$m_2 =$ 6 kg
$m_3 =$ 7 kg

(a)

$$I_A = \sum_{i=1}^{3} m_i r_i^2 = m_1(0)^2 + m_2(3)^2 + m_3(5)^2$$

$$I_A = 6 \cdot 9 + 7 \cdot 25 = \underline{229\ kg \cdot m^2}$$

$$I_B = m_1(5)^2 + m_2(4)^2 + m_3(0)^2$$

$$= 9 \cdot 25 + 6 \times 16 = \underline{321\ kg \cdot m^2}$$

(b)

$$\tau_A = -F\,l_A = -424 \cdot 3m = \underline{-1272\ N \cdot m}$$

$$\tau_B = F\,l_B = 424 \cdot 0 = \underline{0\ N \cdot m}$$

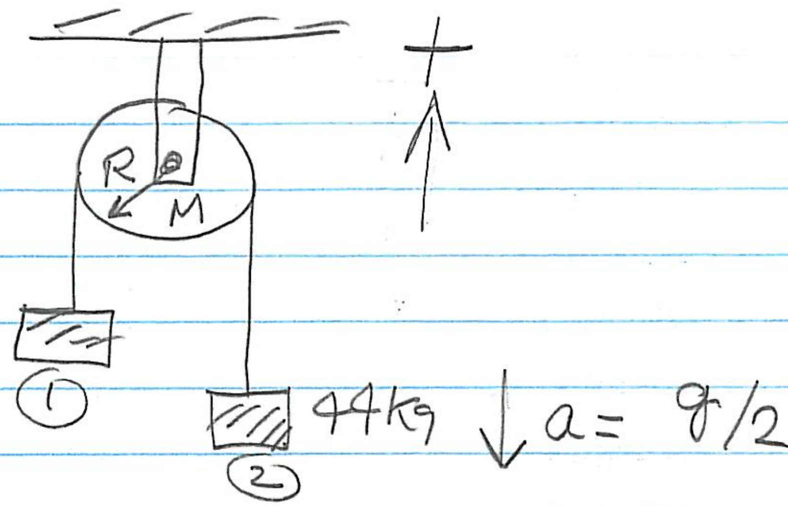
(c)

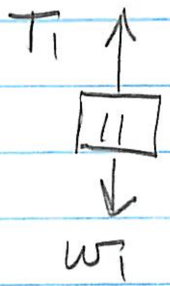
$$\alpha_A = \tau_A / I_A = -1272/229 = \underline{-5.55\ r/s^2}$$

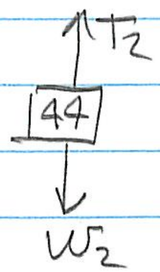
$$\omega_A = \alpha_A t = -5.55 \cdot 5s = \underline{-27.8\ rAD/s}$$

$$\underline{\alpha_B = 0,\ \omega_B = 0}$$

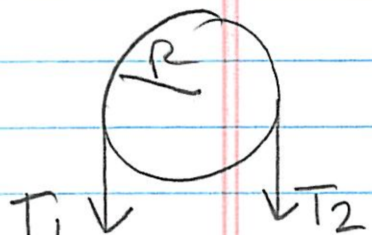
$\boxed{9-47}$







$$\begin{cases} T_1 - w_1 = m_1 a_1 & (1) \\ T_2 - w_2 = m_2 a_2 & (2) \\ a_1 = g/2, \quad a_2 = -g/2 \end{cases}$$



$$I_{pulley} = \tfrac{1}{2} M R^2$$

CW

$-a/R$

$$\sum \tau = T_1 R - T_2 R = I_{pulley}\, \alpha$$

$$(T_1 - T_2)\cancel{R} = \tfrac{1}{2} M R^{\cancel{2}} \cdot \left(-\, a/\cancel{R}\right) \qquad (3)$$

Use (1) & (2) in (3)

$$\left[m_1 \frac{g}{2} + w_1 - \left(-m_2 g/2 + w_2\right)\right] = -\tfrac{1}{2} M a$$

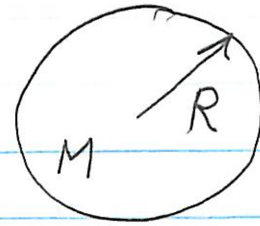
$$m_1 \frac{g}{2} + m_1 g + m_2 \frac{g}{2} - m_2 g = -\tfrac{1}{2} M a$$

$$\left(3/2\, m_1 - 1/2\, m_2\right)\cancel{g} = -\tfrac{1}{2} M \cancel{g}/2$$

X 2 $\quad 3 m_1 - m_2 = -\tfrac{1}{2} M$

$$33 - 44 = -\frac{M}{2} \Rightarrow \underline{M = 22\ kg}$$

$\boxed{9\text{-}49}$



$$KE = \frac{1}{2} I \omega^2$$

$$I = \frac{1}{2} M R^2$$

$$KE = \frac{1}{2}\left(\frac{1}{2} M R^2\right)\omega^2$$

$$1.2 \times 10^9 \text{ J} = \frac{1}{4} \cdot 13 \text{ kg} \cdot (0.3 \text{ m})^2 \omega^2$$

$$1.2 \times 10^9 \text{ J} = 0.29 \omega^2$$

$$\omega = 6.41 \times 10^4 \text{ RAD/S}$$

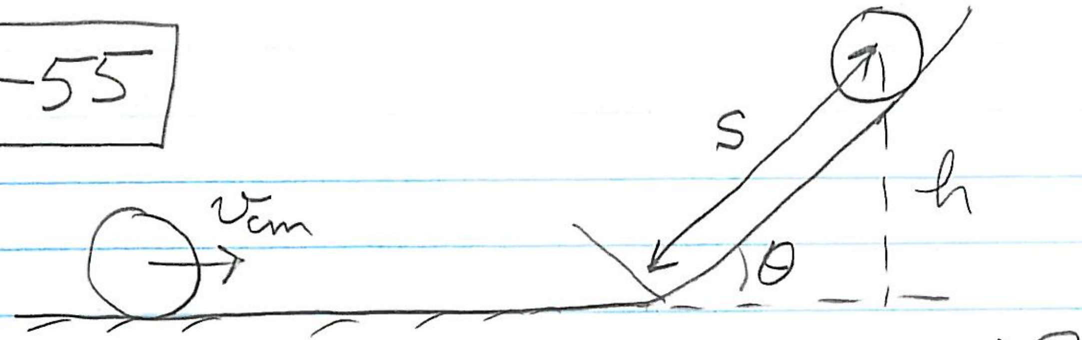
$$1 \frac{\text{RAD}}{\text{S}} = \frac{1\cancel{\text{RAD}}}{\cancel{\text{S}}} \times \frac{1 \text{ ReV}}{2\pi \cancel{\text{RAD}}} \times \frac{60 \text{s}}{\text{min}} = \frac{60}{2\pi} \frac{\text{reV}}{\text{min}}$$

$$= 9.55 \text{ rev/min}$$

$$\omega = 6.41 \times 10^4 \frac{\text{RAD}}{\text{SEC}} \times \frac{9.55 \text{ rev/min}}{\text{RAD/S}}$$

$$= 6.1 \times 10^5 \text{ Rev/min}$$

$\boxed{9-55}$



$h = s \sin\theta$

$E_0 = E_f$

$\frac{1}{2} M v_{cm}^2 + \frac{1}{2} I \omega^2 = Mgh$

$v_{cm} = \omega R$

$I_{disk} = \frac{1}{2} MR^2 \ , \ I_{hoop} = MR^2$

$\frac{1}{2} M v_{cm}^2 + \frac{1}{2} I \frac{v_{cm}^2}{R^2} = Mgh$

Disk $\quad \frac{1}{2} \cancel{M} v_{cm}^2 + \frac{1}{2}\left(\frac{1}{2} \cancel{M} \cancel{R^2}\right) \frac{v_{cm}^2}{\cancel{R^2}} = \cancel{M} gh$

$v_{cm}^2 + \frac{v_{cm}^2}{2} = 2gh$

$\frac{3}{2} v_{cm}^2 = 2gh \Rightarrow v_{cm}^2 = \frac{4}{3} gh$

Hoop $\quad \frac{1}{2} \cancel{M} v_{cm}^2 + \frac{1}{2}(\cancel{M} \cancel{R^2}) \frac{v_{cm}^2}{\cancel{R^2}} = \cancel{M} gh$

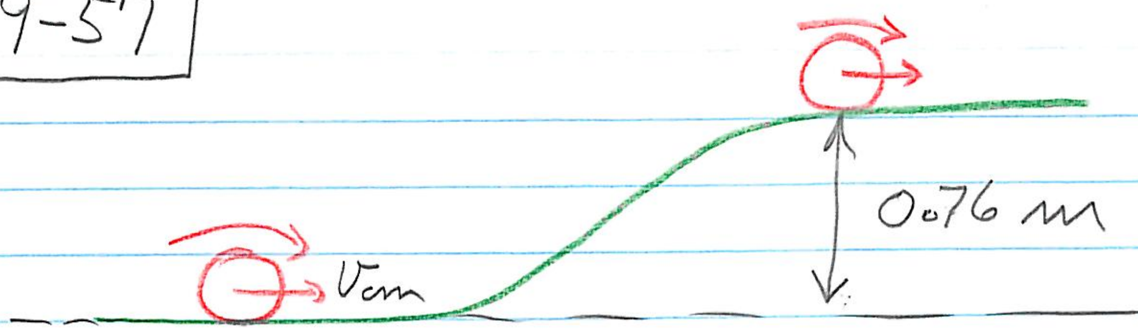
$v_{cm}^2 + v_{cm}^2 = 2gh$

$2 v_{cm}^2 = 2gh \Rightarrow v_{cm}^2 = gh$

$\frac{s_{disk}}{s_{hoop}} = \frac{h_{DISK}}{h_{HOOP}} = \frac{\frac{3}{4}}{1} = \underline{\frac{3}{4}}$

hoop goes higher

$\boxed{9\text{-}57}$



$v_{cm_0} = 3.5\,m/s$

$$E_0 = E_f$$

$$\tfrac{1}{2} m v_{cm_0}^2 + \tfrac{1}{2} I \omega_0^2 = mgh + \tfrac{1}{2} m v_{cm_f}^2 + \tfrac{1}{2} I \omega_f^2$$

$$I_{sphere} = \tfrac{2}{5} m R^2$$

$$v_{cm} = \omega R$$

$$\cancel{\tfrac{1}{2}}\cancel{m}\, v_{cm,0}^2 + \cancel{\tfrac{1}{2}}\left(\tfrac{2}{5}\cancel{m}\cancel{R^2}\right)\frac{v_{cm_0}^2}{\cancel{R^2}}$$

$$= 2\cancel{m}gh + \cancel{\tfrac{1}{2}}\cancel{m}\, v_{cm_f}^2 + \cancel{\tfrac{1}{2}}\left(\tfrac{2}{5}\cancel{m}\cancel{R^2}\right)\frac{v_{cm_f}^2}{\cancel{R^2}}$$

$$v_{cm,0}^2 + \tfrac{2}{5} v_{cm,0}^2 = v_{cm_f}^2 + \tfrac{2}{5} v_{cm_f}^2 + gh$$

$$\tfrac{7}{5} v_{cm,0}^2 = \tfrac{7}{5} v_{cm,f}^2 + 2gh$$

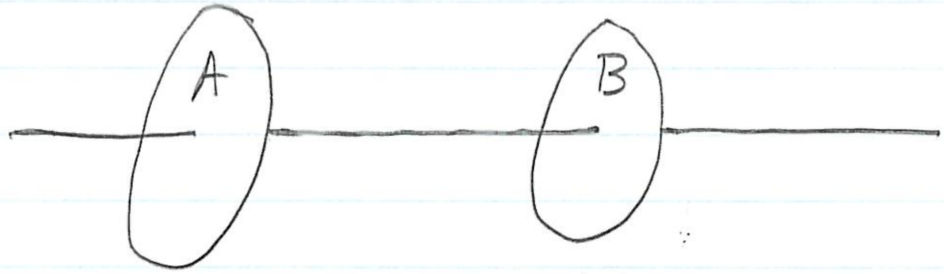
$$v_{cm,f}^2 = v_{cm,0}^2 - \tfrac{5}{7}\cdot 2gh$$

$$= (3.5)^2 - \tfrac{5}{7}\cdot 2 \cdot 9.8 \cdot 0.76 = 1.61\, m^2/s^2$$

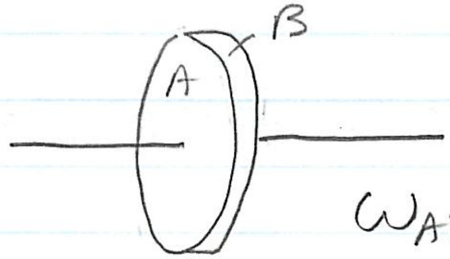
$\underline{v_{cm,f} = 1.3\, m/s}$

$\boxed{9\text{-}59}$

$I_A = 3.4\ kg\,m^2$



$\omega_A = +7.2\ rad/s$ $\qquad$ $\omega_B = -9.8\ rad/s$



$\omega_{AB} = -2.4\ rad/s$

Since there are no external torques involved in the coupling process, the angular momentum is CONSERVED.

$$L_0 = L_f \Rightarrow I_A\omega_A + I_B\omega_B = I_{AB}\omega_{AB}$$

$$I_{AB} = I_A + I_B \quad \text{(Combined } I = \text{Sum of } I\text{'s)}$$

$$I_A\omega_A + I_B\omega_B = (I_A + I_B)\omega_{AB}$$

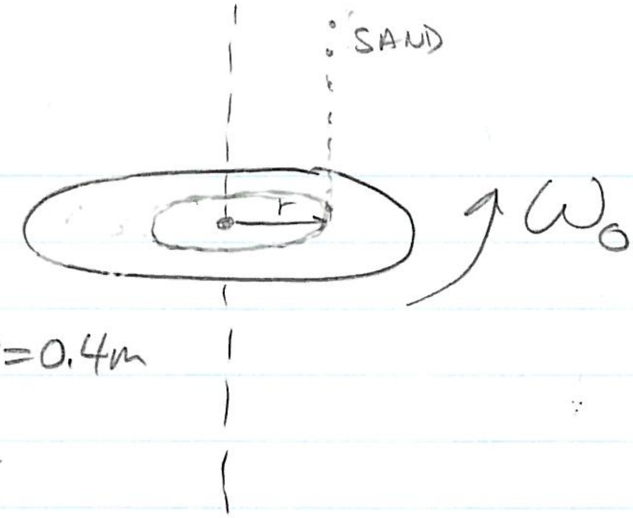
$$I_A(\omega_A - \omega_{AB}) = I_B(\omega_{AB} - \omega_B)$$

$$3.4[7.2-(-2.4)] = I_B[-2.4-(-9.8)]$$

$$32.6 = I_B(7.4)$$

$$I_B = 4.4\ kg\,m^2$$

$\boxed{9\text{-}60}$



$m_s = 0.5\ kg$, $r = 0.4m$

$I_0 = 0.1\ kg\,m^2$

$\omega_0 = 0.067\ rad/s$

$$L_0 = L_f$$

$$I_0 \omega_0 = (I_0 + I_{SAND})\,\omega_f$$

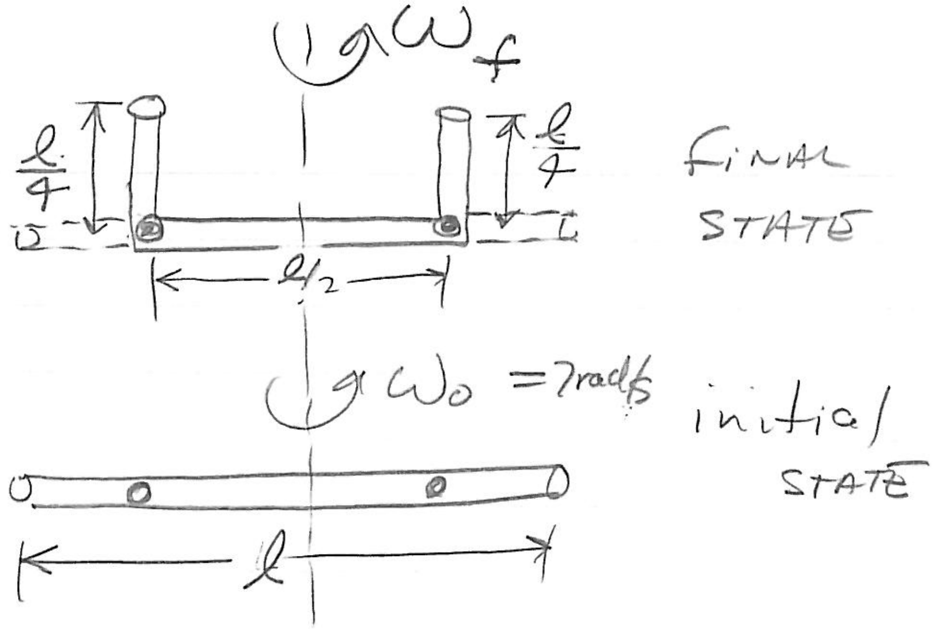
$$I_{sand} = m r^2$$

$$\omega_f = \frac{I_0 \omega_0}{I_0 + m r^2}$$

$$= \frac{0.1 \times 0.067}{0.1 + 0.5(0.4)^2}$$

$$\omega_f = 0.037\ rad/s$$

9-66



The moment of inertia of a thin rod of mass M, length ℓ rotating about an axis passing perpendicular to its center is

$$I = \frac{1}{12} M\ell^2 \quad \text{(TABLE 9-1)}$$

$$L_0 = L_f$$

$$I_0 \omega_0 = I_f \omega_f$$

Since the vertical sections of the "U" are both at the same distance from the axis ($\ell/4$) their contribution to I_f is $2\left[\left(\frac{M}{4}\right)\left(\frac{\ell}{4}\right)^2\right] = M\ell^2/32$

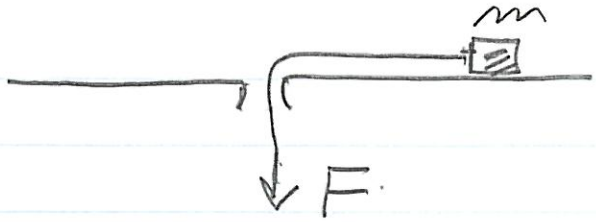
Then $I_U = M\ell^2/32 + \frac{1}{12}\left(\frac{M}{2}\right)\left(\frac{\ell}{2}\right)^2$

$$I_f = M\ell^2\left(\frac{1}{32} + \frac{1}{96}\right) = \frac{1}{24} M\ell^2$$

$$\Rightarrow \frac{1}{12}\cancel{M\ell^2}\omega_0 = \frac{1}{24}\cancel{M\ell^2}\omega_f \rightarrow \omega_f = \frac{24}{12}\omega_0$$

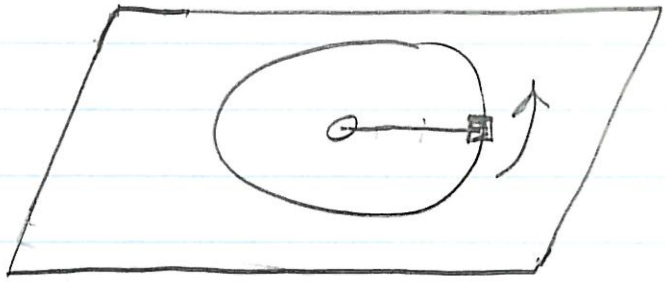
$$\underline{\omega_f = 14 \text{ rad/s}}$$

$\boxed{9\text{-}67}$



SIDE VIEW

$m = 0.5\,kg$
$r_0 = 1.0\,m$
$\omega_0 = 6.28\,rad/s$



Top VIEW

As the string is pulled down and the mass rotates in a smaller and smaller circle, its angular momentum stays constant.

When the radius is r

$$L_0 = L_f \Rightarrow I_0\omega_0 = I\omega$$

$$\cancel{m}r_0^2\omega_0 = \cancel{m}r^2\omega \Rightarrow \omega = (r_0/r)^2\omega_0$$

The tension in the cord provides the centripetal force on m.

$$T = \frac{mv^2}{r} = \frac{m(\omega r)^2}{r} = mr\omega^2$$

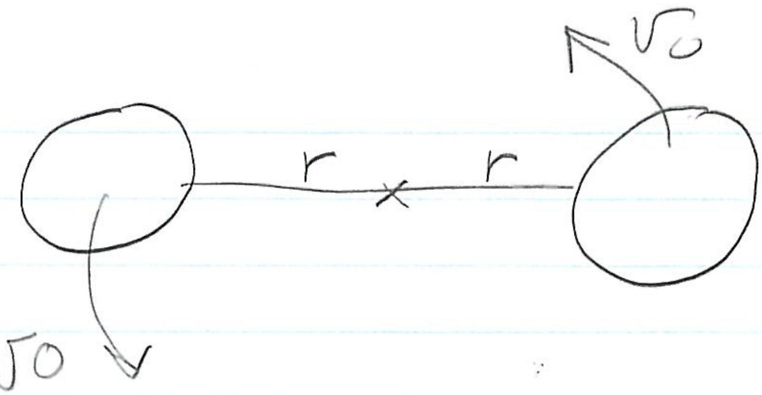
$$T = mr\left(\frac{r_0}{r}\right)^4\omega_0^2 = \frac{mr_0^4\omega_0^2}{r^3}$$

$T < 105N$

$$r^3 > \frac{mr_0^4\omega_0^2}{T} = \frac{0.5(1)^4(6.28)^2}{105N} = 0.188$$

$\boxed{r > 0.57m}$

$\boxed{9\text{-}77}$



$$L_0 = L_f \Rightarrow I_0\omega_0 = I_f\omega_f$$

$$\Rightarrow \cancel{2}(\cancel{m}\, r_0^2)\omega_0 = \cancel{2}(\cancel{m}\, r_f^2)\omega_f$$

$$v_0 = \omega_0 r_0$$

$$r_0^{\cancel{2}} \frac{v_0}{\cancel{r_0}} = r_f^{\cancel{2}} \frac{v_f}{\cancel{r_f}}$$

$$v_f = \left(\frac{r_0}{r_f}\right) v_0$$

$$= 2v_0$$

$$\boxed{v_f = 34\ m/s}$$ for each module.