CHAPTER 9

1. From the force diagram for the sapling we can write

$\cdot F_x = F_1 - F_2 \sin 20° - F_3 \cos \alpha = 0;$

$282 \text{ N} - (355 \text{ N}) \sin 20° - F_3 \cos \alpha = 0$, or

$F_3 \cos \alpha = 161 \text{ N}.$

$\cdot F_y = F_2 \cos 20° - F_3 \sin \alpha = 0;$

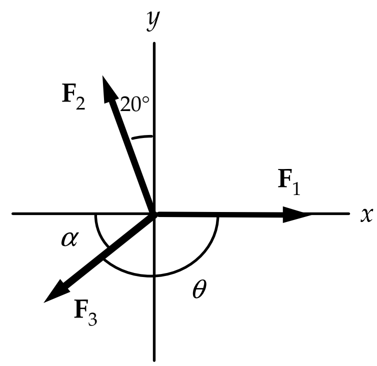
$F_3 \sin \alpha = 334 \text{ N}.$

Thus we have

$F_3 = [(161 \text{ N})^2 + (334 \text{ N})^2]^{1/2} =$ 370 N.

$\tan \alpha = (334 \text{ N})/(161 \text{ N}) = 2.08, \ \alpha = 64°.$

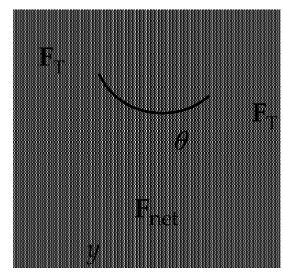
So $\theta = 180° - \alpha =$ 116°.



2. We choose the coordinate system shown, with the y-axis in the direction of the net force. From symmetry we know that the two tensions will be at the same angle from the y-axis.
We write $\cdot F_y = ma_y$ from the force diagram for the tooth:

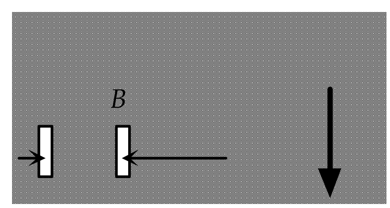
$F_{net} = 2F_T \cos$ (!θ);

$0.75 \text{ N} = 2F_T \cos 77.5°$, which gives $F_T =$ 1.7 N.



3. We choose the coordinate system shown, with positive torques clockwise. For the torque from the person's weight about the point B we have

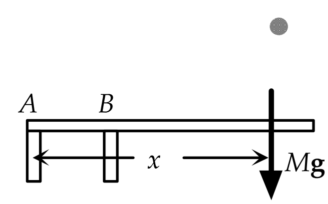
$\tau_B = MgL = (60 \text{ kg})(9.80 \text{ m/s}^2)(3.0 \text{ m}) =$ $1.8 \times 10^3 \text{ m} \cdot \text{N}$.



4. We choose the coordinate system shown, with positive torques clockwise. For the torque from the person's weight about the point A we have

$\tau_A = Mgx;$

$1000 \text{ m} \cdot \text{N} = (60 \text{ kg})(9.80 \text{ m/s}^2)x$, which gives $x =$ 1.7 m.



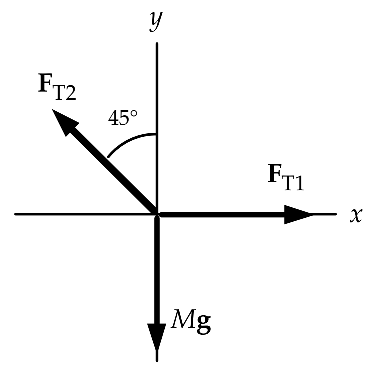
5. From the force diagram for the junction we can write

   $\cdot F_x = F_{T1} - F_{T2} \cos 45° = 0.$

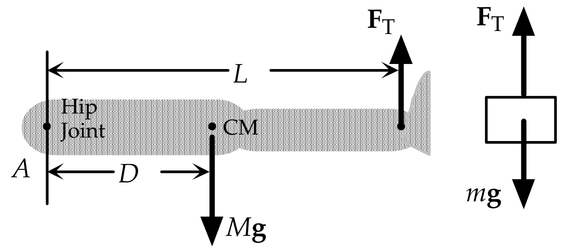
   This shows that $F_{T2} > F_{T1}$, so we take F_{T2} to be the maximum.

   $\cdot F_y = F_{T2} \sin 45° - Mg = 0;$

   $Mg = (1300 \text{ N}) \sin 45° = 9.2 \times 10^2 \text{ N}.$



6. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point A from the force diagram for the leg:



$\cdot\tau_A = MgD - F_T L = 0;$

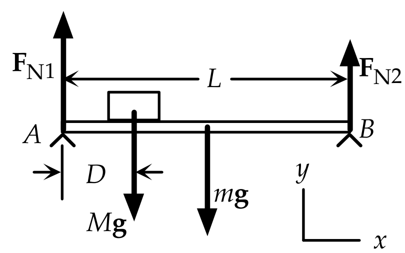
$(15.0\ \text{kg})(9.80\ \text{m/s}^2)(0.350\ \text{m}) - F_T(0.805\ \text{m}),$

which gives $F_T = 63.9$ N.

Because there is no acceleration of the hanging mass, we have

$F_T = mg$, or $m = F_T/g = (63.9\ \text{N})/(9.80\ \text{m/s}^2) =$ 6.52 kg.

7. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point A from the force diagram for the beam and piano:



$\cdot\tau_A = Mg(L + mg!L - F_{N2}L = 0$, which gives

$F_{N2} = (Mg + !mg$

$= ((300\ \text{kg})(9.80\ \text{m/s}^2) + !(160\ \text{kg})(9.80\ \text{m/s}^2)$

$= 1.52 \times 10^3$ N.

We write $\cdot F_y = ma_y$ from the force diagram for the beam and piano:

$F_{N1} + F_{N2} - Mg - mg = 0$, which gives

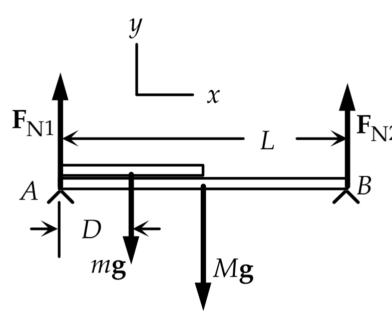
$F_{N1} = Mg + mg - F_{N2}$

$= (300\ \text{kg})(9.80\ \text{m/s}^2) + !(160\ \text{kg})(9.80\ \text{m/s}^2) - 1.52 \times 10^3\ \text{N} = 2.94 \times 10^3$ N.

The forces on the supports are the reactions to these forces:

2.94×10^3 N down, and 1.52×10^3 N down.

8. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point A from the force diagram for the two beams:



$\cdot\tau_A = mg(L + Mg!L - F_{N2}L = 0$, which gives

$F_{N2} = (Mg + !mg$

$= ([!(1000\ \text{kg})](9.80\ \text{m/s}^2) + !(1000\ \text{kg})(9.80\ \text{m/s}^2)$

$=$ 6.13×10^3 N.

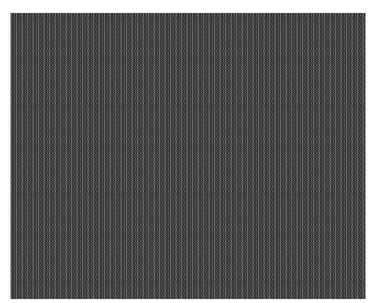
We write $\cdot F_y = ma_y$ from the force diagram for the two beams:

$F_{N1} + F_{N2} - Mg - mg = 0$, which gives

$F_{N1} = Mg + mg - F_{N2}$

$= (1000\ \text{kg})(9.80\ \text{m/s}^2) + !(1000\ \text{kg})(9.80\ \text{m/s}^2) - 6.13 \times 10^3\ \text{N} =$ 8.57×10^3 N.

9. We must move the direction of the net force 10° to the right. We choose the coordinate system shown, with the y-axis in the direction of the original net force.



We write $\cdot\mathbf{F}$ from the force diagram for the tooth:

$\cdot F_x = -F_{T1}\cos 20° + F_{T2}\cos 20° = F_{net}\sin 10°;$

$-(2.0\ \text{N})\cos 20° + F_{T2}\cos 20° = F_{net}\sin 10°;$

$\cdot F_y = +F_{T1}\sin 20° + F_{T2}\sin 20° = F_{net}\cos 10°;$

$+(2.0\ \text{N})\sin 20° + F_{T2}\sin 20° = F_{net}\cos 10°.$

We have two equations for the two unknowns: F_{net}, and F_{T2}.

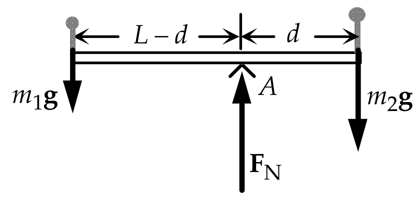
When we eliminate F_{net}, we get $F_{T2} =$ 2.3 N.

10. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the support point A from the force diagram for the board and people:

    $\cdot\tau_A = -m_1g(L - d) + m_2gd = 0;$

    $-(30\text{ kg})(10\text{ m} - d) + (70\text{ kg})d = 0,$

    which gives $d =$ 3.0 m from the adult.

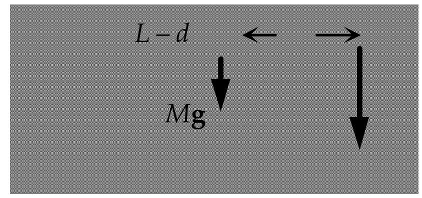


11. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the support point A from the force diagram for the board and people:

    $\cdot\tau_A = -m_1g(L - d) - Mg(!L - d) + m_2gd = 0;$

    $-(30\text{ kg})(10\text{ m} - d) - (15\text{ kg})(5.0\text{ m} - d) + (70\text{ kg})d = 0,$

    which gives $d =$ 3.3 m from the adult.



12. From the force diagram for the mass we can write

    $\cdot F_x = F_{T1} - F_{T2}\cos\theta = 0,$ or

    $F_{T1} = F_{T2}\cos 30°.$

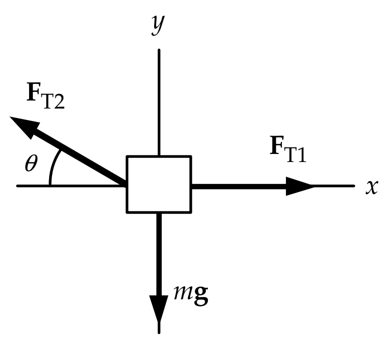
    $\cdot F_y = F_{T2}\sin\theta - mg = 0,$ or

    $F_{T2}\sin 30° = mg = (200\text{ kg})(9.80\text{ m/s}^2),$

    which gives $F_{T2} =$ 3.9×10^3 N.

    Thus we have

    $F_{T1} = F_{T2}\cos 30° = (3.9 \times 10^3\text{ N})\cos 30° =$ 3.4×10^3 N.



13. From the force diagram for the hanging light and junction we can write

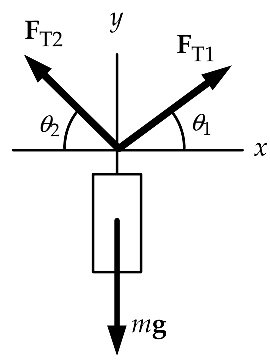
    $\cdot F_x = F_{T1}\cos\theta_1 - F_{T2}\cos\theta_2 = 0;$

    $F_{T1}\cos 37° = F_{T2}\cos 53°;$

    $\cdot F_y = F_{T1}\sin\theta_1 + F_{T2}\sin\theta_2 - mg = 0;$

    $F_{T1}\sin 37° + F_{T2}\sin 53° = (30\text{ kg})(9.80\text{ m/s}^2).$

    When we solve these two equations for the two unknowns, F_{T1}, and F_{T2}, we get $F_{T1} = 1.8 \times 10^2$ N, and $F_{T2} = 2.4 \times 10^2$ N.

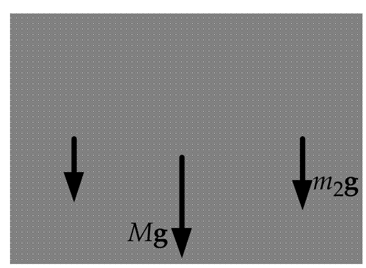


14. From the force diagram for the seesaw and children we can write

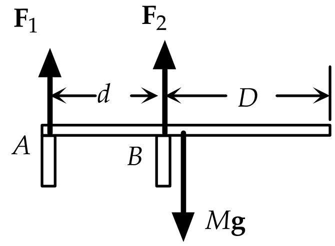
    $\cdot F_y = F_N - m_1g - m_2g - Mg = 0,$ or

    $F_N = (m_1 + m_2 + M)g$

    $= (30\text{ kg} + 25\text{ kg} + 2.0\text{ kg})(9.80\text{ m/s}^2) =$ 5.6×10^2 N.



15. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the support point A from the force diagram for the cantilever:



$\cdot\tau_A = -F_2 d + Mg!L = 0;$

$-F_2(20.0 \text{ m}) + (1200 \text{ kg})(9.80 \text{ m/s}^2)(25.0 \text{ m}) = 0,$

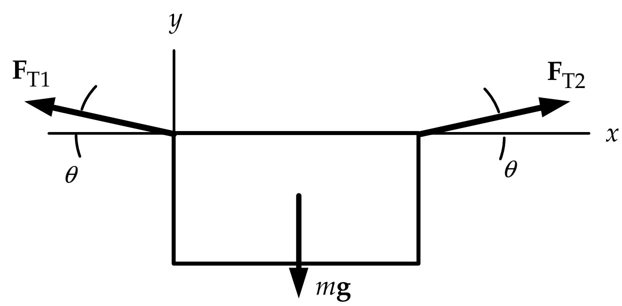
which gives $F_2 =$ 1.47×10^4 N.

For the forces in the y-direction we have

$\cdot F_y = F_1 + F_2 - Mg = 0,$ or

$F_1 = Mg - F_2 = (1200 \text{ kg})(9.80 \text{ m/s}^2) - (1.47 \times 10^4 \text{ N}) =$ -2.94×10^3 N (down).

16. From the force diagram for the sheet we can write



$\cdot F_x = F_{T2} \cos\theta - F_{T1} \cos\theta = 0,$ which gives

$F_{T2} = F_{T1}.$

$\cdot F_y = F_{T1} \sin\theta + F_{T2} \sin\theta - mg = 0;$

$2F_{T1} \sin\theta = mg;$

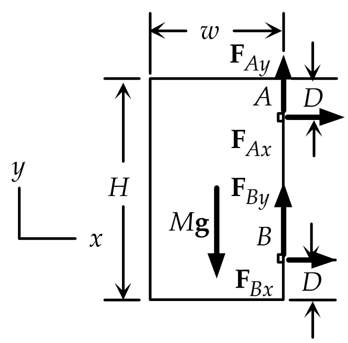
$2F_{T1} \sin 3.5° = (0.60 \text{ kg})(9.80 \text{ m/s}^2),$

which gives $F_{T1} =$ 48 N;

The tension is so much greater than the weight because

only the vertical components balance the weight.

17. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the lower hinge B from the force diagram for the door:



$\cdot\tau_B = F_{Ax}(H - 2D) - Mg!w = 0;$

$F_{Ax}[2.30 \text{ m} - 2(0.40 \text{ m})] - (13.0 \text{ kg})(9.80 \text{ m/s}^2)!(1.30 \text{ m}),$

which gives $F_{Ax} = 55.2$ N.

We write $\cdot\mathbf{F} = m\mathbf{a}$ from the force diagram for the door:

$\cdot F_x = F_{Ax} + F_{Bx} = 0;$

$55 \text{ N} + F_{Bx} = 0,$ which gives $F_{Bx} = -55.2$ N.

The top hinge pulls away from the door, and the bottom hinge pushes on the door.

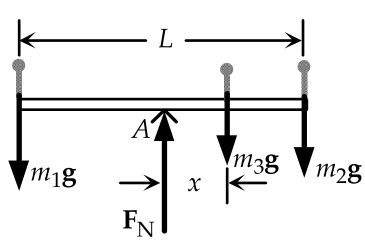
$\cdot F_y = F_{Ay} + F_{By} - Mg = 0.$

Because each hinge supports half the weight, we have

$F_{Ay} = F_{By} = !(3.0 \text{ kg})(9.80 \text{ m/s}^2) = 63.7$ N.

Thus we have top hinge: $F_{Ax} = 55.2$ N, $F_{Ay} = 63.7$ N; bottom hinge: $F_{Ax} = -55.2$ N, $F_{Ay} = 63.7$ N.

18. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the support point A from the force diagram for the seesaw and boys:



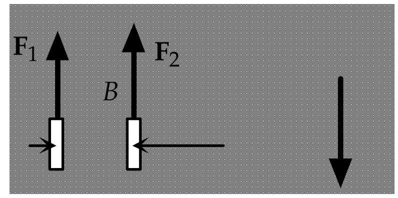
$\cdot\tau_A = +m_2 g!L + m_3 g x - m_1 g!L = 0;$

$+(35 \text{ kg})!(3.6 \text{ m}) + (25 \text{ kg})x - (50 \text{ kg})!(3.6 \text{ m}) = 0,$

which gives $x = 1.1$ m.

The third boy should be 1.1 m from pivot on side of lighter boy.

19. We choose the coordinate system shown, with positive torques clockwise. For the torques about the point B we have



$\Sigma\tau_B = F_1 d + MgD = 0;$

$F_1(1.0\text{ m}) + (60\text{ kg})(9.80\text{ m/s}^2)(3.0\text{ m}) = 0,$

which gives $F_1 = -1.8 \times 10^3\text{ N (down)}.$

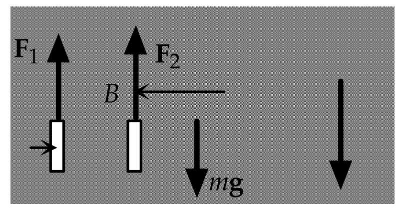
For the torques about the point A we have

$\Sigma\tau_A = -F_2 d + Mg(D + d) = 0;$

$F_2(1.0\text{ m}) = (60\text{ kg})(9.80\text{ m/s}^2)(4.0\text{ m} + 1.0\text{ m}),$

which gives $F_2 = 2.4 \times 10^3\text{ N (up)}.$

20. We choose the coordinate system shown, with positive torques clockwise. For the torques about the point B we have



$\Sigma\tau_B = F_1 d + MgD + mg[\tfrac{1}{2}(D + d) - d] = 0;$

$F_1(1.0\text{ m}) = -(60\text{ kg})(9.80\text{ m/s}^2)(3.0\text{ m}) - (35\text{ kg})(9.80\text{ m/s}^2)(1.0\text{ m}),$

which gives $F_1 = -2.1 \times 10^3\text{ N (down)}.$

For the torques about the point A we have

$\Sigma\tau_A = -F_2 d + MgD + mg\tfrac{1}{2}(D + d) = 0;$

$F_2(1.0\text{ m}) = (60\text{ kg})(9.80\text{ m/s}^2)(3.0\text{ m}) + (35\text{ kg})(9.80\text{ m/s}^2)(2.0\text{ m}),$

which gives $F_2 = 3.0 \times 10^3\text{ N (up)}.$

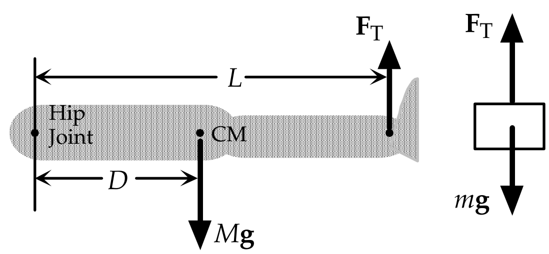
21. From Example 7–16 we have

$D = (20.4/100)(1.60\text{ m}) = 0.326\text{ m}.$

From Table 7–1, we have

$L = [(52.1 - 4.0)/100](1.60\text{ m}) = 0.770\text{ m};$

$M = \tfrac{1}{2}[(21.5 + 9.6 + 3.4)/100](60.0\text{ kg}) = 10.35\text{ kg}.$



We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the hip joint from the force diagram for the leg:

$\Sigma\tau = MgD - F_T L = 0;$

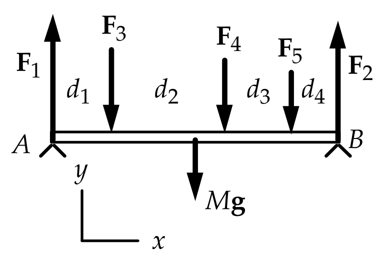
$(10.35\text{ kg})(9.80\text{ m/s}^2)(0.326\text{ m}) - F_T(0.770\text{ m}) = 0.$

which gives $F_T = 42.9\text{ N}.$

Because there is no acceleration of the hanging mass, we have

$F_T = mg,$ or $m = F_T/g = (42.9\text{ N})/(9.80\text{ m/s}^2) = 4.38\text{ kg}.$

22. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the support point B from the force diagram for the beam:



$\Sigma\tau_B = +F_1(d_1 + d_2 + d_3 + d_4) - F_3(d_2 + d_3 + d_4) -$
$F_4(d_3 + d_4) - F_5 d_4 - Mg\tfrac{1}{2}(d_1 + d_2 + d_3 + d_4) = 0;$

$F_1(10.0\text{ m}) - (4000\text{ N})(8.0\text{ m}) - (3000\text{ N})(4.0\text{ m}) -$
$(2000\text{ N})(1.0\text{ m}) - (250\text{ kg})(9.80\text{ m/s}^2)(5.0\text{ m}) = 0,$

which gives $F_1 = 5.8 \times 10^3\text{ N}.$

We write $\Sigma\tau = I\alpha$ about the support point A from the force diagram for the beam:

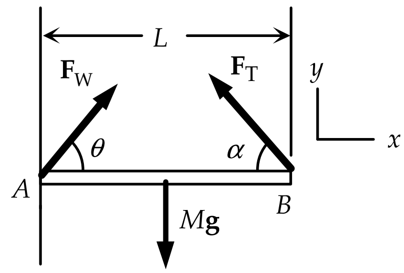
$\Sigma\tau_A = -F_2(d_1 + d_2 + d_3 + d_4) + F_3 d_1 - F_4(d_1 + d_2) -$
$F_5(d_1 + d_2 + d_3) - Mg\tfrac{1}{2}(d_1 + d_2 + d_3 + d_4) = 0;$

$-F_2(10.0\text{ m}) - (4000\text{ N})(2.0\text{ m}) - (3000\text{ N})(6.0\text{ m}) -$

$(2000 \text{ N})(9.0 \text{ m}) - (250 \text{ kg})(9.80 \text{ m/s}^2)(5.0 \text{ m}) = 0,$

which gives $F_2 = 5.6 \times 10^3 \text{ N}.$

23. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point A from the force diagram for the beam:



$\cdot\tau_A = -(F_T \sin\alpha)L + Mg!L = 0;$

$-F_T \sin 50° + (30 \text{ kg})(9.80 \text{ m/s}^2)! = 0,$

which gives $F_T = 1.9 \times 10^2$ N.

Note that we find the torque produced by the tension by finding the torques produced by the components.

We write $\cdot\mathbf{F} = m\mathbf{a}$ from the force diagram for the beam:

$\cdot F_x = F_{Wx} - F_T \cos\alpha = 0;$

$F_{Wx} - (1.9 \times 10^2 \text{ N}) \cos 50° = 0$, which gives $F_{Wx} = 123$ N.

$\cdot F_y = F_{Wy} + F_T \sin\alpha - Mg = 0;$

$F_{Wy} + (1.9 \times 10^2 \text{ N}) \sin 50° - (30 \text{ kg})(9.80 \text{ m/s}^2) = 0$, which gives $F_{Wy} = 147$ N.

For the magnitude of $\mathbf{F}_W$ we have

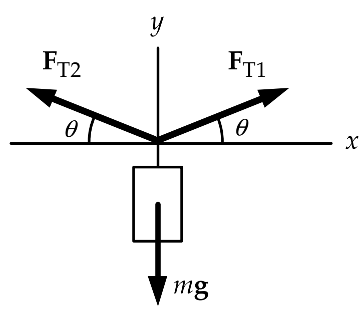
$F_W = (F_{Wx}{}^2 + F_{Wy}{}^2)^{1/2} = [(123 \text{ N})^2 + (147 \text{ N})^2]^{1/2} = 1.9 \times 10^2$ N.

We find the direction from

$\tan\theta = F_{Wy}/F_{Wx} = (147 \text{ N})/(123 \text{ N}) = 1.19$, which gives $\theta = 50°$.

Thus the force at the wall is $\mathbf{F}_W = 1.9 \times 10^2$ N, 50° above the horizontal.

24. Because the backpack is at the midpoint of the rope, the angles are equal. The force exerted by the backpacker is the tension in the rope. From the force diagram for the backpack and junction we can write



$\cdot F_x = F_{T1} \cos\theta - F_{T2} \cos\theta = 0$, or $F_{T1} = F_{T2} = F;$

$\cdot F_y = F_{T1} \sin\theta + F_{T2} \sin\theta - mg = 0$, or

$2F \sin\theta = mg.$

(*a*) We find the angle from

$\tan\theta = h/!L = (1.5 \text{ m})/!(7.6 \text{ m}) = 0.395$, or $\theta = 21.5°$.

When we put this in the force equation, we get

$2F \sin 21.5° = (16 \text{ kg})(9.80 \text{ m/s}^2)$, which gives $F = 2.1 \times 10^2$ N.

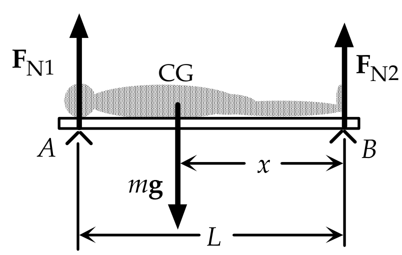
(*b*) We find the angle from

$\tan\theta = h/!L = (0.15 \text{ m})/!(7.6 \text{ m}) = 0.0395$, or $\theta = 2.26°$.

When we put this in the force equation, we get

$2F \sin 2.26° = (16 \text{ kg})(9.80 \text{ m/s}^2)$, which gives $F = 2.0 \times 10^3$ N.

25. We choose the coordinate system shown, with positive torques clockwise. For the torques about the CG we have

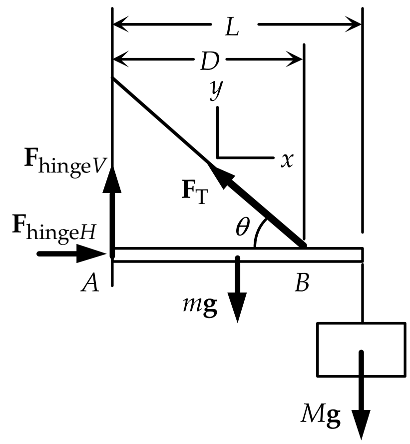


$\cdot\tau_{CG} = F_{N1}(L - x) - F_{N2}x = 0;$

$(35.1 \text{ kg})g(170 \text{ cm} - x) - (31.6 \text{ kg})gx = 0,$

which gives $x = 89.5$ cm from the feet.

26. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the point A from the force diagram for the beam and sign:



$\Sigma\tau_A = -(F_T \sin\theta)D + MgL + mg\tfrac{1}{2}L = 0;$

$-F_T(\sin 41.0°)(1.35\text{ m}) + (215\text{ N})(1.70\text{ m}) + (135\text{ N})\tfrac{1}{2}(1.70\text{ m}) = 0,$

which gives $F_T = 542\text{ N}$.

Note that we find the torque produced by the tension by finding the torques produced by the components.

We write $\Sigma\mathbf{F} = m\mathbf{a}$ from the force diagram for the beam and sign:

$\Sigma F_x = F_{\text{hinge}x} - F_T\cos\theta = 0;$

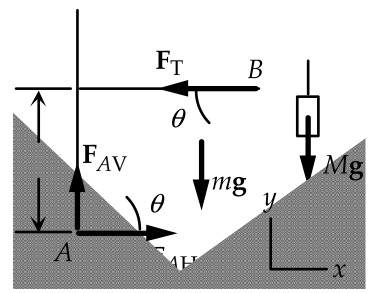
$F_{\text{hinge}x} - (542\text{ N})\cos 41.0° = 0$, which gives $F_{\text{hinge}x} =$ 409 N.

$\Sigma F_y = F_{\text{hinge}y} + F_T\sin\theta - Mg - mg = 0;$

$F_{\text{hinge}y} + (542\text{ N})\cos 41.0° - 215\text{ N} - 135\text{ N} = 0,$

which gives $F_{\text{hinge}y} =$ – 6 N (down).

27. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the point A from the force diagram for the pole and light:



$\Sigma\tau_A = -F_T H + MgL\cos\theta + mg\tfrac{1}{2}L\cos\theta = 0;$

$-F_T(3.80\text{ m}) + (12.0\text{ kg})(9.80\text{ m/s}^2)(7.5\text{ m})\cos 37° +$

$(8.0\text{ kg})(9.80\text{ m/s}^2)\tfrac{1}{2}(7.5\text{ m})\cos 37° = 0,$

which gives $F_T = 2.5\times10^2\text{ N}$.

We write $\Sigma\mathbf{F} = m\mathbf{a}$ from the force diagram for the pole and light:

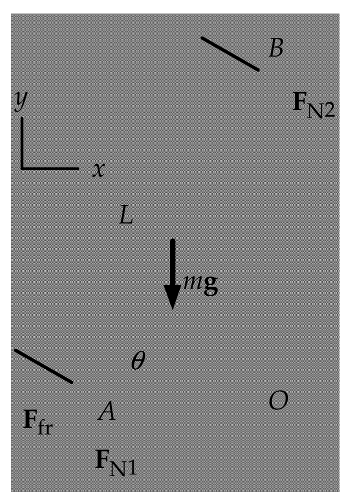
$\Sigma F_x = F_{AH} - F_T = 0;$

$F_{AH} - 2.5\times10^2\text{ N} = 0$, which gives $F_{AH} =$ $2.5\times10^2\text{ N}$.

$\Sigma F_y = F_{AV} - Mg - mg = 0;$

$F_{AV} - (12.0\text{ kg})(9.80\text{ m/s}^2) - (8.0\text{ kg})(9.80\text{ m/s}^2) = 0$, which gives $F_{AV} =$ $2.0\times10^2\text{ N}$.

28. We choose the coordinate system shown, with positive torques counterclockwise. We write $\Sigma\tau = I\alpha$ about the point A from the force diagram for the ladder:



$\Sigma\tau_A = mg(\tfrac{1}{2}L)\cos\theta - F_{N2}L\sin\theta = 0$, which gives

$F_{N2} = mg/2\tan\theta.$

We write $\Sigma F_x = ma_x$ from the force diagram for the ladder:

$F_{fr} - F_{N2} = 0$, which gives $F_{fr} = F_{N2} = mg/2\tan\theta$.

We write $\Sigma F_y = ma_y$ from the force diagram for the ladder:

$F_{N1} - mg = 0$, which gives $F_{N1} = mg$.

For the bottom not to slip, we must have

$F_{fr} \le \mu F_{N1}$, or $mg/2\tan\theta \le \mu mg$,

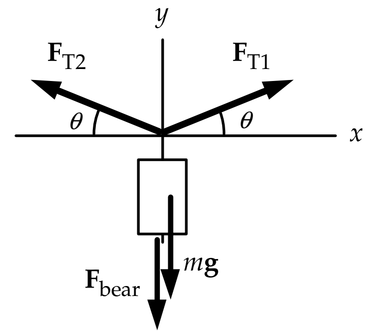
from which we get $\tan\theta \ge 1/2\mu$.

The minimum angle is $\theta_{\min} = \tan^{-1}(1/2\mu)$.

29. Because the backpack is at the midpoint of the rope, the angles are equal. From the force diagram for the backpack and junction we can write

$\cdot F_x = F_{T1} \cos\theta - F_{T2} \cos\theta = 0$, or $F_{T1} = F_{T2} = F$;

$\cdot F_y = F_{T1} \sin\theta + F_{T2} \sin\theta - mg - F_{bear} = 0$.



When the bear is not pulling, we have

$2F_1 \sin\theta = mg$;

$2F_1 \sin 15° = (23.0\text{ kg})(9.80\text{ m/s}^2)$, which gives $F_1 = 435$ N.

When the bear is pulling, we have

$2F_2 \sin\theta = mg + F_{bear}$;

$2(2)(435\text{ N}) \sin 30° = (23.0\text{ kg})(9.80\text{ m/s}^2) + F_{bear}$,

which gives $F_{bear} =$ 6.5×10^2 N.

30. We choose the coordinate system shown, with positive torques clockwise.

(*a*) For the torques about the point *B* we have

$\cdot \tau_B = F_{T1}(!L + D) - MgD = 0$;

$F_{T1}(0.500\text{ m} + 0.400\text{ m}) - (0.230\text{ kg})(9.80\text{ m/s}^2)(0.400\text{ m}) = 0$,

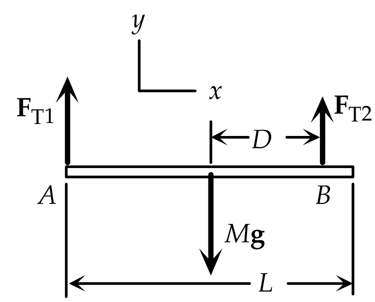
which gives $F_{T1} =$ 1.00 N.

(*b*) For the torques about the point *A* we have

$\cdot \tau_A = -F_{T2}(!L + D) + Mg!L = 0$;

$-F_{T2}(0.500\text{ m} + 0.400\text{ m}) + (0.230\text{ kg})(9.80\text{ m/s}^2)(0.500\text{ m})$,

which gives $F_{T2} =$ 1.25 N.



31. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point *A* from the force diagram for the ladder and painter:

$\cdot \tau_A = mg(!d_L) + Mgd_P - F_W h_L = 0$;

$(12.0\text{ kg})(9.80\text{ m/s}^2)!(3.0\text{ m}) + (60.0\text{ kg})(9.80\text{ m/s}^2)(2.1\text{ m}) - F_W(4.0\text{ m}) = 0$,

which gives $F_W = 353$ N.

We write $\cdot F_x = ma_x$ from the force diagram:

$F_{Gx} - F_W = 0$, which gives

$F_{Gx} = F_W = 353$ N.

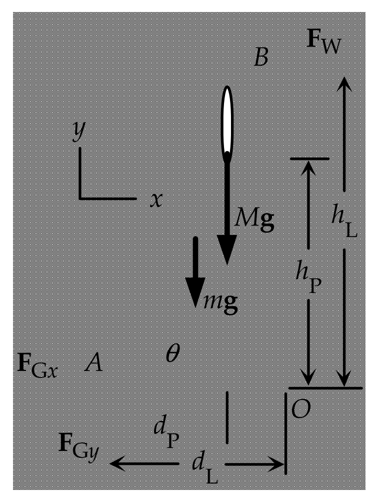
We write $\cdot F_y = ma_y$ from the force diagram:

$F_{Gy} - mg - Mg = 0$, which gives

$F_{Gy} = (m + M)g = (12.0\text{ kg} + 60.0\text{ kg})(9.80\text{ m/s}^2) = 706$ N.

Because the ladder is on the verge of slipping, we must have

$F_{Gx} = \mu F_{Gy}$, or $\mu = F_{Gx}/F_{Gy} = (353\text{ N})/(706\text{ N}) =$ 0.50.

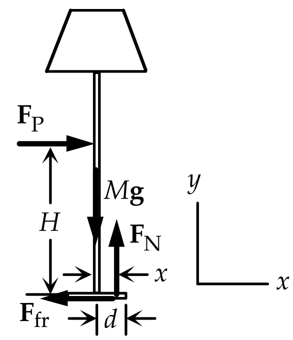


32. We choose the coordinate system shown, with positive torques clockwise.
We write $\cdot F_x = ma_x$ from the force diagram for the lamp:

$F_P - F_{fr} = 0$, which gives $F_P = F_{fr}$.

We write $\cdot F_y = ma_y$ from the force diagram for the lamp:

$F_N - mg = 0$, which gives $F_N = mg$.



(*a*) If we assume that the lamp slides, we have $F_P = F_{fr} = \mu F_N = \mu mg$.
The normal force would have to be inside the base, so we find the distance from the pole at which it acts. We write $\cdot \tau = I\alpha$ about the center of the base from the force diagram for the lamp:

$\cdot \tau = F_P H - F_N x = \mu mgH - mgx = 0$;

$(0.20)(0.60 \text{ m}) - \ x = 0$, which gives $x = 0.12$ m.

Because this is greater than 0.10 m, the lamp will tip over.

(*b*) If the lamp slides, we have $F_P = F_{fr} = \mu F_N = \mu mg$.
We write $\cdot \tau = I\alpha$ about the center of the base from the force diagram for the lamp:

$\cdot \tau = F_P H - F_N x = \mu mgH - mgx = 0$, or $H = x/\mu$.

The maximum height will be when x is maximum, which is d:

$H_{max} = d/\mu = (0.10 \text{ m})/(0.20) = 0.50 \text{ m} =$ 50 cm.

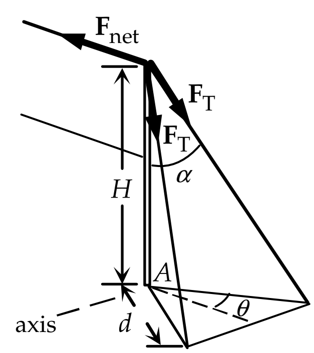
33. From the symmetry of the wires, we see that the angle between a horizontal line on the ground parallel to the net and the line from the base of the pole to the anchoring point is $\theta = 30°$. We find the angle between the pole and a wire from

$\tan \alpha = d/H = (2.0 \text{ m})/(2.6 \text{ m}) = 0.769$, which gives $\alpha = 37.6°$.

Thus the horizontal component of each tension is $F_T \sin \alpha$.
We write $\cdot \tau = I\alpha$ about the horizontal axis through the base A perpendicular to the net from the force diagram for the pole:

$\cdot \tau_A = F_{net}H - 2(F_T \sin \alpha \cos \theta)H = 0$, or

$F_{net} = 2F_T \sin \alpha \cos \theta = 2(95 \text{ N}) \sin 37.6° \cos 30° =$ 1.0×10^2 N.

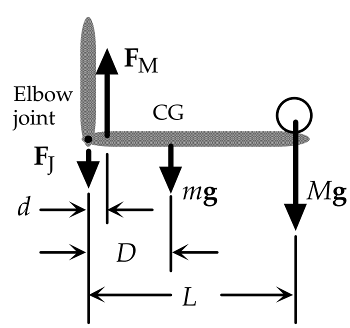


34. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot \tau = I\alpha$ about the elbow joint from the force diagram for the lower arm:

$\cdot \tau = mgD + MgL - F_M d = 0$;

$(2.0 \text{ kg})(9.80 \text{ m/s}^2)(0.15 \text{ m}) + M(9.80 \text{ m/s}^2)(0.35 \text{ m}) - (400 \text{ N})(0.060 \text{ m}) = 0$,

which gives $M =$ 6.1 kg.

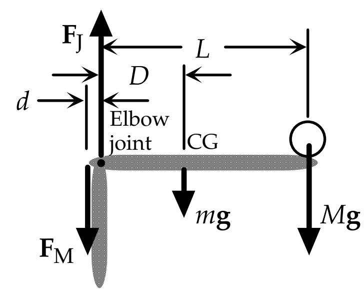


35. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the elbow joint from the force diagram for the lower arm:

$\Sigma\tau = mgD + MgL - F_M d = 0;$

$(2.8\text{ kg})(9.80\text{ m/s}^2)(0.12\text{ m}) + (7.3\text{ kg})(9.80\text{ m/s}^2)(0.300\text{ m}) - F_M(0.025\text{ m}) = 0,$

which gives $F_M =$ 9.9×10^2 N.

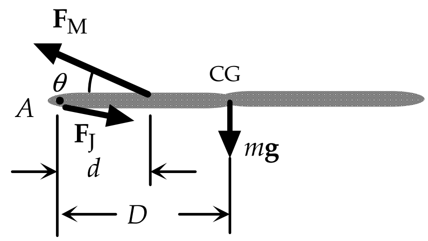


36. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the shoulder joint A from the force diagram for the arm:

    $\Sigma\tau_A = mgD - (F_M \sin\theta)d = 0;$

    $(3.3\text{ kg})(9.80\text{ m/s}^2)(0.24\text{ m}) - (F_M \sin 15°)(0.12\text{ m}) = 0,$

    which gives $F_M =$ 2.5×10^2 N.



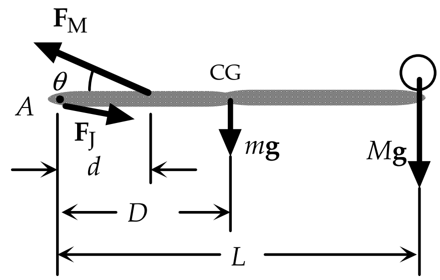
37. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the shoulder joint A from the force diagram for the arm:

    $\Sigma\tau_A = mgD + MgL - (F_M \sin\theta)d = 0;$

    $(3.3\text{ kg})(9.80\text{ m/s}^2)(0.24\text{ m}) + (15\text{ kg})(9.80\text{ m/s}^2)(0.52\text{ m}) - (F_M \sin 15°)(0.12\text{ m}) = 0,$

    which gives $F_M =$ 2.7×10^3 N.

    Note that this is more than 10 times the result from Problem 36.



38. We write $\Sigma F_x = ma_x$ from the force diagram:

    $F_{Jx} - F_M \cos\theta = 0$, which gives $F_{Jx} = F_M \cos\theta$.

    We write $\Sigma F_y = ma_y$ from the force diagram:

    $F_{Jy} + F_M \sin\theta - mg - Mg = 0,$

    which gives $F_{Jy} = (m + M)g - F_M \sin\theta$.

    For Problem 36, $M = 0$, so we have

    $F_{Jx} = F_M \cos\theta = (2.5 \times 10^2\text{ N}) \cos 15° = 241\text{ N}.$

    $F_{Jy} = (m + M)g - F_M \sin\theta$

    $= (3.3\text{ kg})(9.80\text{ m/s}^2) - (2.5 \times 10^2\text{ N}) \sin 15° = -32\text{ N}.$

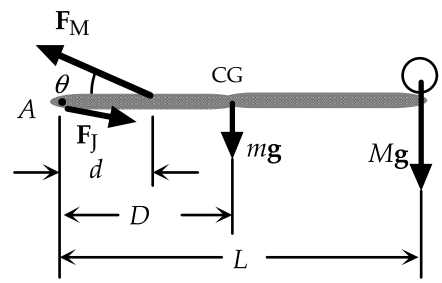
    $F_J = (F_{Jx}^2 + F_{Jy}^2)^{1/2} = [(241\text{ N})^2 + (-32\text{ N})^2]^{1/2} =$ 2.4×10^2 N.

    For Problem 37, $M = 15$ kg, so we have

    $F_{Jx} = F_M \cos\theta = (2.7 \times 10^3\text{ N}) \cos 15° = 2.61 \times 10^3\text{ N}.$

    $F_{Jy} = (m + M)g - F_M \sin\theta = (3.3\text{ kg} + 15\text{ kg})(9.80\text{ m/s}^2) - (2.7 \times 10^3\text{ N}) \sin 15° = -517\text{ N}.$

    $F_J = (F_{Jx}^2 + F_{Jy}^2)^{1/2} = [(2.61 \times 10^3\text{ N})^2 + (-517\text{ N})^2]^{1/2} =$ 2.7×10^3 N.



39. Because the person is standing on one foot, the normal force on the ball of the foot must support the weight: $F_N = Mg$. We choose the coordinate system shown, with positive torques clockwise. We write $\Sigma\tau = I\alpha$ about the point A from the force diagram for the foot:

    $\Sigma\tau_A = F_T d - F_N D = 0;$

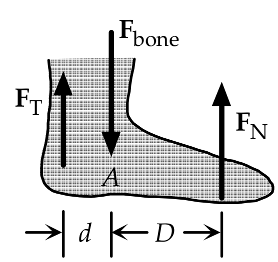
    $F_T d - F_N(2d) = 0$, which gives

    $F_T = 2F_N = 2(70\text{ kg})(9.80\text{ m/s}^2) =$ 1.4×10^3 N (up).

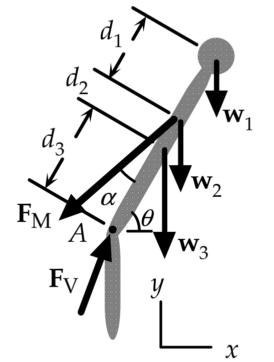
    We write $\Sigma F_y = ma_y$ from the force diagram:

    $F_T + F_N - F_{bone} = 0$, which gives

    $F_{bone} = F_T + F_N = 3F_N = 3(70\text{ kg})(9.80\text{ m/s}^2) =$ 2.1×10^3 N (down).



40. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point A from the force diagram for the torso:



$$\cdot\tau_A = w_1(d_1 + d_2 + d_3)\cos\theta + w_2(d_2 + d_3)\cos\theta + w_3 d_3 \cos\theta - (F_M \sin\alpha)(d_2 + d_3) = 0;$$

$$0.07w(24\text{ cm} + 12\text{ cm} + 36\text{ cm})\cos 60° + 0.12w(12\text{ cm} + 36\text{ cm})\cos 60° + 0.46w(36\text{ cm})\cos 60° - F_M(\sin 12°)(12\text{ cm} + 36\text{ cm}) = 0,$$

which gives $F_M = 1.37w$.

We write $\cdot F_x = ma_x$ from the force diagram:

$F_{Vx} - F_M \cos(\theta - \alpha) = 0$, which gives

$F_{Vx} = F_M \cos(\theta - \alpha) = (1.37w)\cos 48° = 0.917w.$

We write $\cdot F_y = ma_y$ from the force diagram:

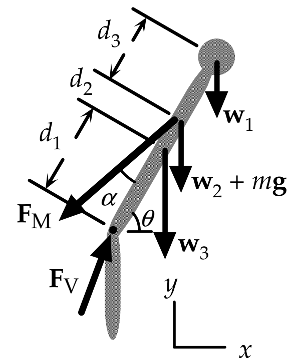
$F_{Vy} - F_M \sin(\theta - \alpha) - w_1 - w_2 - w_3 = 0$, which gives

$F_{Vy} = F_M \sin(\theta - \alpha) + w_1 + w_2 + w_3 = (1.37w)\sin 48° + 0.07w + 0.12w + 0.46w = 1.67w.$

For the magnitude we have

$F_V = (F_{Vx}^2 + F_{Vy}^2)^{1/2} = [(0.917w)^2 + (1.67w)^2]^{1/2} =$ $1.9w$.

41. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the point A from the force diagram for the torso:



$$\cdot\tau_A = w_1(d_1 + d_2 + d_3)\cos\theta + (w_2 + mg)(d_2 + d_3)\cos\theta + w_3 d_3 \cos\theta - (F_M \sin\alpha)(d_2 + d_3) = 0;$$

$$0.07(70\text{ kg})(9.80\text{ m/s}^2)(24\text{ cm} + 12\text{ cm} + 36\text{ cm})\cos 30° + [0.12(70\text{ kg}) + 20\text{ kg}](9.80\text{ m/s}^2)(12\text{ cm} + 36\text{ cm})\cos 30° + 0.46(70\text{ kg})(9.80\text{ m/s}^2)(36\text{ cm})\cos 30° - F_M(\sin 12°)(12\text{ cm} + 36\text{ cm}) = 0,$$

which gives $F_M = 2.45 \times 10^3$ N.

We write $\cdot F_x = ma_x$ from the force diagram:

$F_{Vx} - F_M \cos(\theta - \alpha) = 0$, which gives

$F_{Vx} = F_M \cos(\theta - \alpha) = (2.45 \times 10^3\text{ N})\cos 18° = 2.33 \times 10^3$ N.

We write $\cdot F_y = ma_y$ from the force diagram:

$F_{Vy} - F_M \sin(\theta - \alpha) - w_1 - w_2 - w_3 - mg = 0$, which gives

$F_{Vy} = F_M \sin(\theta - \alpha) + w_1 + w_2 + w_3 + mg$

$= (2.45 \times 10^3\text{ N})\sin 18° + (0.07 + 0.12 + 0.46)(70\text{ kg})(9.80\text{ m/s}^2) + (20\text{ kg})(9.80\text{ m/s}^2) = 1.40 \times 10^3$ N.

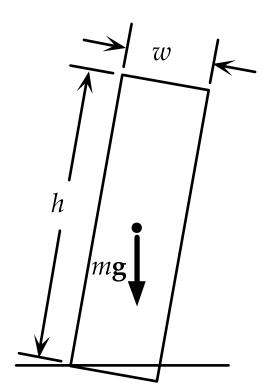
For the magnitude we have

$F_V = (F_{Vx}^2 + F_{Vy}^2)^{1/2} = [(2.33 \times 10^3\text{ N})^2 + (1.40 \times 10^3\text{ N})^2]^{1/2} =$ 2.7×10^3 N.

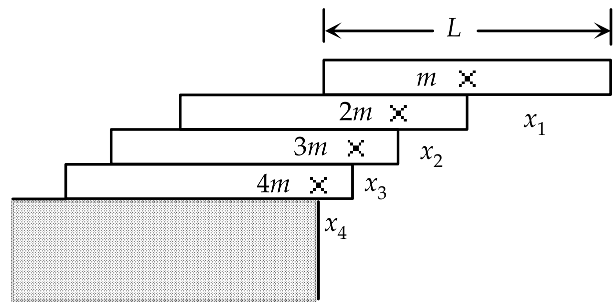
42. If the tower is of uniform composition, the center of gravity will be at the center of the tower. Because the top is 4.5 m off center, the CG will be !(4.5 m) = 2.25 m off center. This is less than the radius of the tower, 3.5 m, so the line of the weight is inside the base and the tower is in stable equilibrium.

The tower will become unstable when the CG is off center by half the diameter, or the top is off center by the diameter. Thus the tower can lean an additional

7.0 m – 4.5 m = 2.5 m.



43. (*a*) The maximum distance for the top brick to remain on the next brick will be reached when its center of mass is directly over the edge of the next brick. Thus the top brick will overhang by $x_1 = L/2$.



The maximum distance for the top two bricks to remain on the next brick will be reached when the center of mass of the top two bricks is directly over the edge of the third brick. If we take the edge of the third brick as the origin, we have

$x_{CM} = [m(x_2 - L/2) + mx_2]/2m = 0$, which gives $x_2 = L/4$.

The maximum distance for the top three bricks to remain on the next brick will be reached when the center of mass of the top three bricks is directly over the edge of the fourth brick. If we take the edge of the fourth brick as the origin, we have

$x_{CM} = [m(x_3 - L/2) + 2mx_3]/3m = 0$, which gives $x_3 = L/6$.

The maximum distance for the four bricks to remain on the table will be reached when the center of mass of the four bricks is directly over the edge of the table. If we take the edge of the table as the origin, we have

$x_{CM} = [m(x_4 - L/2) + 3mx_4]/3m = 0$, which gives $x_4 = L/8$.

(*b*) With the origin at the table edge, we find the position of the left edge of the top brick from

$D = x_1 + x_2 + x_3 + x_4 - L = (L/2) + (L/4) + (L/6) + (L/8) - L = L/24$, which is beyond the table.

(*c*) We can generalize our results by recognizing that the *i*th brick is a distance $L/2i$ beyond the edge of the brick below it. The total distance spanned by *n* bricks is

$$D = L\sum_{i=1}^{n} \frac{1}{2i}.$$

(*d*) Each side of the arch must span 0.50 m. From our general result, we have

$$0.50 \text{ m} = (0.30 \text{ m})\sum_{i=1}^{n} \frac{1}{2i}.$$

If we evaluate this numerically, such as by using a spreadsheet, we find that 16 bricks will create a span of 0.507 m, so a minimum of 32 bricks is necessary, not counting the one on top. If the bottom brick is flush with the opening, as shown in Fig. 9–32, then two more bricks will be needed.

44. We find the increase in length from the elastic modulus:

E = Stress/Strain = $(F/A)/(ÆL/L_0)$;

5×10^9 N/m² = [(250 N)/¹(0.50 × 10⁻³ m)²]/[ÆL/(30.0 cm)], which gives ÆL = 1.91 cm.

45. (*a*) We find the stress from

Stress = F/A = (25,000 kg)(9.80 m/s²)/(2.0 m²) = 1.2×10^5 N/m².

(*b*) We find the strain from

Strain = Stress/E = (1.2×10^5 N/m²)/(50×10^9 N/m²) = 2.4×10^{-6}.

46. We use the strain to find how much the column is shortened:

Strain = $ÆL/L_0$;

2.4×10^{-6} = ÆL/(12 m), which gives ÆL = 2.9×10^{-5} m = 0.029 mm.

47. (*a*) We find the stress from

Stress = F/A = (2000 kg)(9.80 m/s^2)/(0.15 m^2) = 1.3×10^5 N/m^2.

(*b*) We find the strain from

Strain = Stress/E = (1.3×10^5 N/m^2)/(200×10^9 N/m^2) = 6.6×10^{-7}.

(*c*) We use the strain to find how much the girder is lengthened:

Strain = ÆL/L_0;

6.5×10^{-7} = ÆL/(9.50 m), which gives ÆL = 6.2×10^{-6} m = 0.0062 mm.

48. The tension in each wire produces the stress. We find the strain from

Strain = Stress/E = F_T/EA.

For wire 1 we have

Strain$_1$ = (1.8×10^2 N)/(200×10^9 N/m^2)¹(0.50×10^{-3} m)^2 = 1.15×10^{-3} = 0.12%.

For wire 2 we have

Strain$_2$ = (2.4×10^2 N)/(200×10^9 N/m^2)¹(0.50×10^{-3} m)^2 = 1.53×10^{-3} = 0.15%.

49. We find the volume change from

ÆP = – B ÆV/V_0;

(2.6×10^6 N/m^2 – 1.0×10^5 N/m^2) = – (1.0×10^9 N/m^2)ÆV/(1000 cm^3),

which gives ÆV = – 2.5 cm^3.

The new volume is V_0 + ÆV = 1000 cm^3 + (– 2.5 cm^3) = 997 cm^3.

50. We find the elastic modulus from

E = Stress/Strain = (F/A)/(ÆL/L_0)

= [(13.4 N)/(¹(8.5×10^{-3} m)^2]/[(0.37 cm)/(15 cm)] = 9.6×10^6 N/m^2.

51. The pressure needed is determined by the bulk modulus:

ÆP = – B ÆV/V_0 = – (90×10^9 N/m^2)(– 0.10×10^{-2}) = 9.0×10^7 N/m^2.

This is (9.0×10^7 N/m^2)/(1.0×10^5 N/m$^2 \cdot$ atm) = 9.0×10^2 atm.

52. We will take the change in pressure to be 200 atm. We find the volume change from

ÆP = – B ÆV/V_0;

(200 atm)(1.0×10^5 N/m$^2 \cdot$ atm) = – (90×10^9 N/m^2)ÆV/V_0,

which gives ÆV/V_0 = – 2.2×10^{-4} = – 0.022%.

53. If we treat the abductin as an elastic spring, we find the effective spring constant from

k = F/ÆL = EA/L_0 = (2.0×10^6 N/m^2)(0.50×10^{-4} m^2)/(3.0×10^{-3} m) = 3.33×10^4 N/m.

We find the elastic potential energy stored in the abductin from

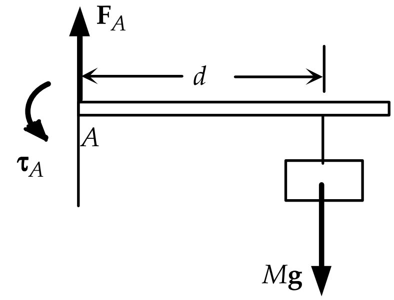
PE = !kx^2 = !(3.33×10^4 N/m)(1.0×10^{-3} m)^2 = 0.017 J.

54. (*a*) For the torque from the sign's weight about the point A we have

$\tau_A = Mgd = (5.1\ \text{kg})(9.80\ \text{m/s}^2)(2.2\ \text{m}) =$ $1.1 \times 10^2\ \text{m}\cdot\text{N}$.

(*b*) The balancing torque must be exerted by the wall, which is the only other contact point. Because the torque from the sign is clockwise, this torque must be counterclockwise.

(*c*) If we think of the torque from the wall as a pull on the top of the pole and a push on the bottom of the pole, there is tension along the top of the pole and compression along the bottom. There must also be a vertical force at the wall which, in combination with the weight of the sign, will create a shear stress in the pole. Thus all three play a part.



55. We find the maximum compressive force from the compressive strength of bone:

$F_{max} = (\text{Compressive strength})A = (170 \times 10^6\ \text{N/m}^2)(3.0 \times 10^{-4}\ \text{m}^2) =$ $5.1 \times 10^4\ \text{N}$.

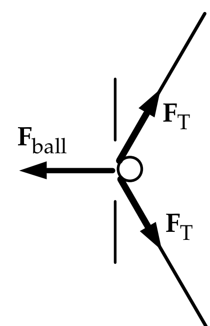
56. We find the maximum tension from the tensile strength of nylon:

$F_{Tmax} = (\text{Tensile strength})A$

$= (500 \times 10^6\ \text{N/m}^2)^1(0.50 \times 10^{-3}\ \text{m})^2 =$ $3.9 \times 10^2\ \text{N}$.

We can increase the maximum tension by increasing the area, so we use thicker strings.

The impulse on the ball that changes its momentum must be provided by an increased tension, so that the maximum strength is exceeded.



57. (*a*) We determine if the compressive strength, $1.7 \times 10^8\ \text{N/m}^2$, is exceeded:

Stress $= F/A = (3.6 \times 10^4\ \text{N})/(3.6 \times 10^{-4}\ \text{m}^2) = 1.0 \times 10^8\ \text{N/m}^2$.

Because this is less than the compressive strength, the bone will not break.

(*b*) We find the change in length from

Strain $= ÆL/L_0 = \text{Stress}/E$, or

$ÆL = (\text{Stress})L_0/E = (1.0 \times 10^8\ \text{N/m}^2)(0.20\ \text{m})/(15 \times 10^9\ \text{N/m}^2) = 1.3 \times 10^{-3}\ \text{m} =$ 1.3 mm.

58. (*a*) We want the maximum stress to be (1/7.0) of the tensile strength:

$\text{Stress}_{max} = F/A_{min} = (\text{Tensile strength})/7.0$;

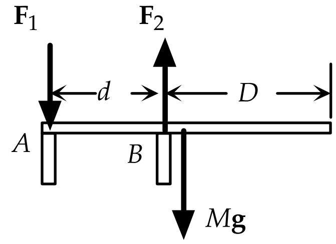
$(320\ \text{kg})(9.80\ \text{m/s}^2)/A_{min} = (500 \times 10^6\ \text{N/m}^2)/7.0$, which gives $A_{min} =$ $4.4 \times 10^{-5}\ \text{m}^2$.

(*b*) We find the change in length from

Strain $= ÆL/L_0 = \text{Stress}/E$, or

$ÆL = (\text{Stress})L_0/E = [(500 \times 10^6\ \text{N/m}^2)/7.0](7.5\ \text{m})/(200 \times 10^9\ \text{N/m}^2) = 2.7 \times 10^{-3}\ \text{m} =$ 2.7 mm.

59. We choose the coordinate system shown, with positive torques clockwise. We write $\cdot\tau = I\alpha$ about the support point A from the force diagram for the cantilever:



$\cdot\tau_A = -F_2 d + Mg!L = 0;$

$-F_2(20.0\text{ m}) + (2600\text{ kg})(9.80\text{ m/s}^2)(25.0\text{ m}) = 0,$

which gives $F_2 = 3.19 \times 10^4$ N.

We assume the force is parallel to the grain. We want the maximum stress to be (1/8.5) of the compressive strength:

$\text{Stress}_{\text{max2}} = F/A_{\text{min2}} = (\text{Compressive strength})/8.5;$

$(3.19 \times 10^4\text{ N})/A_{\text{min2}} = (35 \times 10^6\text{ N/m}^2)/8.5$, which gives $A_{\text{min2}} = 7.7 \times 10^{-3}\text{ m}^2$.

For the forces in the y-direction we have

$\cdot F_y = F_1 + F_2 - Mg = 0,$ or

$F_1 = Mg - F_2 = (2600\text{ kg})(9.80\text{ m/s}^2) - (3.19 \times 10^4\text{ N}) = -6.42 \times 10^3\text{ N}.$

We assume the force is parallel to the grain. We want the maximum stress to be (1/8.5) of the tensile strength:

$\text{Stress}_{\text{max1}} = F/A_{\text{min1}} = (\text{Tensile strength})/8.5;$

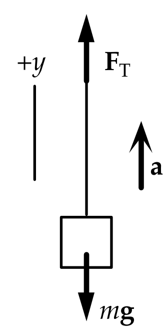
$(6.42 \times 10^3\text{ N})/A_{\text{min1}} = (40 \times 10^6\text{ N/m}^2)/8.5$, which gives $A_{\text{min1}} = 1.4 \times 10^{-3}\text{ m}^2$.

60. We want the maximum shear stress to be (1/6.0) of the shear strength:

$\text{Stress}_{\text{max}} = F/A_{\text{min}} = (\text{Shear strength})/6.0;$

$(3200\text{ N})/(^1 d_{\text{min}}{}^2 = (170 \times 10^6\text{ N/m}^2)/6.0$, which gives $d_{\text{min}} = 1.2 \times 10^{-2}\text{ m} =$ 1.2 cm.

61. We find the required tension from $\cdot F_y = ma_y$:



$F_\text{T} - mg = ma,$ or

$F_\text{T} = m(a + g) = (3100\text{ kg})(1.2\text{ m/s}^2 + 9.80\text{ m/s}^2) = 3.41 \times 10^4\text{ N}.$

We want the maximum stress to be (1/7.0) of the tensile strength:

$\text{Stress}_{\text{max}} = F/A_{\text{min}} = (\text{Tensile strength})/7.0;$

$(3.41 \times 10^4\text{ N})/(^1 d_{\text{min}}{}^2 = (500 \times 10^6\text{ N/m}^2)/7.0,$

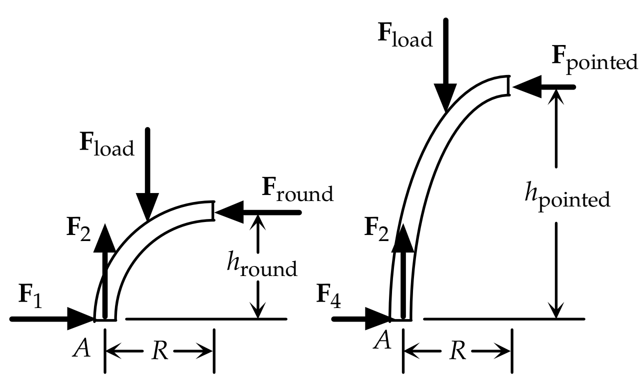
which gives $d_{\text{min}} = 2.5 \times 10^{-2}\text{ m} =$ 2.5 cm.

62. In each arch the horizontal force at the base must equal the horizontal force at the top. Because the two arches support the same load, we see from the force diagrams that the vertical forces will be the same and have the same moment arms. Thus the torque about the base of the horizontal force at the top must be the same for the two arches:

$\tau = F_{\text{round}} h_{\text{round}} = F_{\text{round}} R = F_{\text{pointed}} h_{\text{pointed}};$

$F_{\text{round}}(4.0\text{ m}) = @F_{\text{round}} h_{\text{pointed}},$

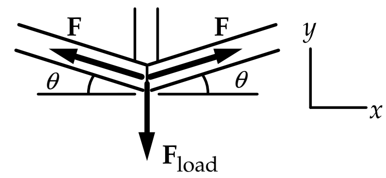
which gives $h_{\text{pointed}} =$ 12 m.



63. We find the required tension from $\Sigma F_y = ma_y$:

$2F \sin \theta - F_{\text{load}} = 0;$

$2F \sin 5° - 4.3 \times 10^5\ \text{N} = 0$, which gives $F =$ $2.5 \times 10^6\ \text{N}$.



64. All elements are in equilibrium. For the C-D pair, we write $\Sigma\tau = I\alpha$ about the point c from the force diagram:

$\Sigma\tau_c = M_C g L_6 - M_D g L_5 = 0;$

$M_C(5.00\ \text{cm}) - M_D(17.50\ \text{cm}) = 0$, or $M_C = 3.500 M_D$.

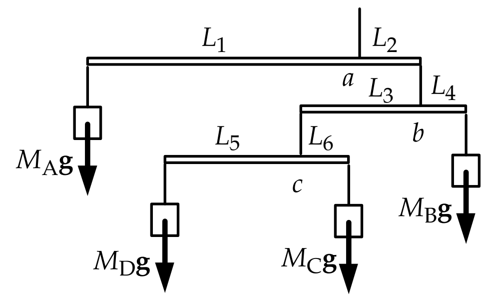
The center of mass of C and D must be under the point c.

We write $\Sigma\tau = I\alpha$ about the point b from the force diagram:

$\Sigma\tau_b = M_B g L_4 - (M_C + M_D) g L_3 = 0;$

$(0.735\ \text{kg})(5.00\ \text{cm}) - (M_C + M_D)(15.00\ \text{cm}) = 0$, or

$M_C + M_D = 0.245\ \text{kg}.$



When we combine these two results, we get $M_C = 0.191\ \text{kg}$, and $M_D = 0.0544\ \text{kg}$.

The center of mass of B, C, and D must be under the point b. For the entire mobile, we write $\Sigma\tau = I\alpha$ about the point a from the force diagram:

$\Sigma\tau_a = (M_B + M_C + M_D) g L_2 - M_A g L_1 = 0;$

$(0.735\ \text{kg} + 0.245\ \text{kg})(7.50\ \text{cm}) - M_A(30.00\ \text{cm}) = 0$, which gives $M_A = 0.245\ \text{kg}$.

65. We choose the coordinate system shown, with positive torques clockwise.

We write $\Sigma\tau$ about the rear edge from the force diagram:

$\Sigma\tau_{\text{edge}} = mg\tfrac{1}{2}L - F_A\tfrac{1}{2}H$

$= (1.8 \times 10^8\ \text{N})\tfrac{1}{2}(40\ \text{m}) - (950\ \text{N/m}^2)(200\ \text{m})(70\ \text{m})\tfrac{1}{2}(200\ \text{m})$

$= + 2.3 \times 10^9\ \text{m} \cdot \text{N}.$

Because the result is positive, the torque is clockwise, so the building will not topple.

An alternative procedure is to find the location of the force $F_{Ey} = mg$.

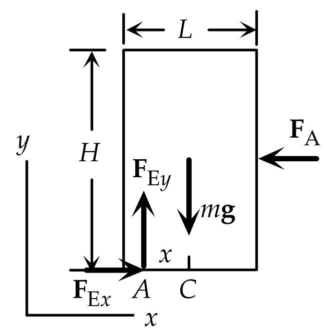
We write $\Sigma\tau = 0$ about the middle of the base from the force diagram:

$\Sigma\tau_C = F_{Ey}x - F_A\tfrac{1}{2}H = 0;$

$(1.8 \times 10^8\ \text{N})x - (950\ \text{N/m}^2)(200\ \text{m})(70\ \text{m})\tfrac{1}{2}(200\ \text{m}) = 0,$

which gives $x = 11$ m.

Because this is less than 20 m, the building will not topple.



66. Because the walker is at the midpoint of the rope, the angles are equal. We find the angle from

$\tan \theta = h/\tfrac{1}{2}L = (3.4\ \text{m})/\tfrac{1}{2}(46\ \text{m}) = 0.148$, or $\theta = 8.41°$.

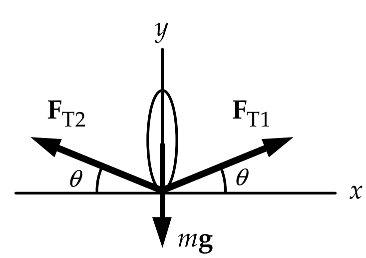
From the force diagram for the walker we can write

$\Sigma F_x = F_{T1} \cos \theta - F_{T2} \cos \theta = 0$, or $F_{T1} = F_{T2} = F_T;$

$\Sigma F_y = F_{T1} \sin \theta + F_{T2} \sin \theta - mg = 0$, or

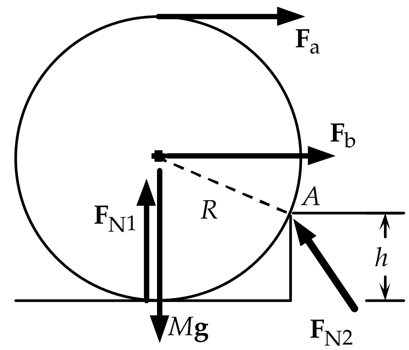
$2F_T \sin 8.41° = (60\ \text{kg})(9.80\ \text{m/s}^2)$, which gives

$F_T = 2.0 \times 10^3\ \text{N}.$



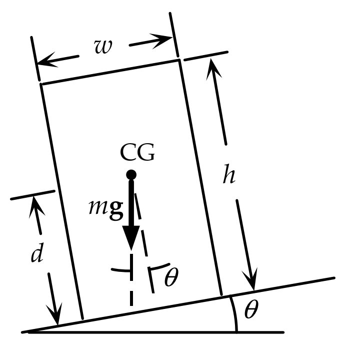
No. There must always be an upward component of the tension to balance the weight.

67. (*a*) The cylinder will roll about the contact point A.
We write $\Sigma\tau = I\alpha$ about the point A:
$F_a(2R - h) + F_{N1}[R^2 - (R - h)^2]^{1/2} - Mg[R^2 - (R - h)^2]^{1/2} = I_A\alpha.$
When the cylinder does roll over the curb, contact with the ground is lost and $F_{N1} = 0$. Thus we get
$F_a = \{I_A\alpha + Mg[R^2 - (R - h)^2]^{1/2}\}/(2R - h)$
$= [I_A\alpha/(2R - h)] + [Mg(2Rh - h^2)^{1/2}/(2R - h)].$
The minimum force occurs when $\alpha = 0$:
$F_{a\min} = Mg[h(2R - h)]^{1/2}/(2R - h) =$ $Mg[h/(2R - h)]^{1/2}$.



(*b*) The cylinder will roll about the contact point A.
We write $\Sigma\tau = I\alpha$ about the point A:
$F_b(R - h) + F_{N1}[R^2 - (R - h)^2]^{1/2} - Mg[R^2 - (R - h)^2]^{1/2} = I_A\alpha.$
When the cylinder does roll over the curb, contact with the ground is lost and $F_{N1} = 0$. Thus we get
$F_b = \{I_A\alpha + Mg[R^2 - (R - h)^2]^{1/2}\}/(R - h)$
$= [I_A\alpha/(R - h)] + [Mg(2Rh - h^2)^{1/2}/(R - h)].$
The minimum force occurs when $\alpha = 0$:
$F_{b\min} =$ $Mg[h(2R - h)]^{1/2}/(R - h)$.

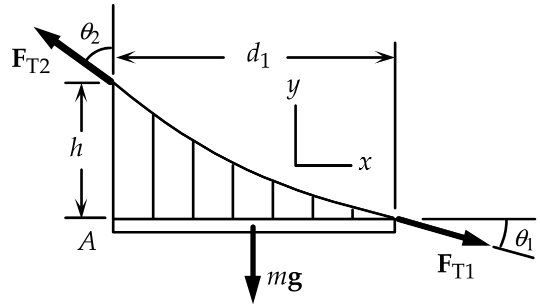
68. If the vertical line of the weight falls within the base of the truck, it will not tip over. The limiting case will be when the line passes through the corner of the base. Thus we find the limiting angle from
$\tan\theta_{max} = !w/d = !(2.4\text{ m})/(2.2\text{ m}) = 0.545$, or $\theta_{max} = 29°$.



69. (*a*) From Example 7–7, the force of the ground on one leg is
$F_{leg} = !(2.1 \times 10^5\text{ N}) = 1.05 \times 10^5\text{ N}.$
We find the stress in the tibia bone from
Stress $= F_{leg}/A = (1.05 \times 10^5\text{ N})/(3.0 \times 10^{-4}\text{ m}) =$ $3.5 \times 10^8\text{ N/m}^2$.
(*b*) The compressive strength of bone is $1.7 \times 10^8\text{ N/m}^2$. Thus the bone will break.
(*c*) From Example 7–7, the force of the ground on one leg is
$F_{leg} = !(4.9 \times 10^3\text{ N}) = 2.45 \times 10^3\text{ N}.$
We find the stress in the tibia bone from
Stress $= F_{leg}/A = (2.45 \times 10^3\text{ N})/(3.0 \times 10^{-4}\text{ m}) =$ $8.2 \times 10^6\text{ N/m}^2$.
This is less than the compressive strength of bone, so the bone will not break.

70. The force is parallel to the grain. We want the maximum stress to be (1/12) of the compressive strength. For N studs we have
Stress$_{max} = (Mg/N)/A =$ (Compressive strength)/12;
$(12{,}600\text{ kg})(9.80\text{ m/s}^2)/N(0.040\text{ m})(0.090\text{ m}) = (35 \times 10^6\text{ N/m}^2)/12$, which gives $N = 11.8$.
Thus we need 6 studs on each side.
There are five spaces between the studs, so they will be
$(10.0\text{ m})/5 =$ 2.0 m apart.

71. From the force diagram for the section we can write



$·F_x = F_{T1} \cos\theta_1 - F_{T2} \sin\theta_2 = 0$, or

$F_{T1} \cos 19° - F_{T2} \sin 60° = 0$;

$·F_y = - F_{T1} \sin\theta_1 + F_{T2} \cos\theta_2 - mg = 0$, or

$- F_{T1} \sin 19° + F_{T2} \cos 60° = mg$.

When we combine these equations, we get

$F_{T1} = 4.54mg$, and $F_{T2} = 4.96mg$.

We write $·\tau = I\alpha$ about the point A from the force diagram:

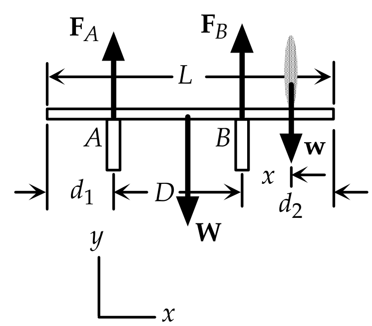
$·\tau_A = - (F_{T2} \sin\theta_2)h + (F_{T1} \sin\theta_1)d_1 + mg!d_1 = 0$;

$- (4.96mg \sin 60°)h + (4.54mg \sin 19°)(343 \text{ m}) + mg!(343 \text{ m}) = 0$,

which gives $h = 158$ m.

72. We choose the coordinate system shown, with positive torques clockwise.

(*a*) The maximum weight will cause the force F_A to be zero.



We write $·\tau = I\alpha$ about the support point B from the force diagram for the beam and person:

$·\tau_B = - W(!L - d_2) + wd_2 + F_A D = 0$;

$- (600 \text{ N})[!(20.0 \text{ m}) - 5.0 \text{ m}] + w_{max}(5.0 \text{ m}) + 0 = 0$,

which gives $w_{max} =$ 600 N.

(*b*) The maximum weight means the force $F_A = 0$.

We write $·\tau = I\alpha$ about the support point A from the force diagram for the beam and person:

$·\tau_A = + W(!L - d_1) + w(D - d_2) - F_B D = 0$;

$+ (600 \text{ N})[!(20.0 \text{ m}) - 3.0 \text{ m}] + (600 \text{ N})(5.0 \text{ m}) - F_B(12.0 \text{ m}) = 0$,

which gives $F_B = 1200$ N.

(*c*) We write $·\tau = I\alpha$ about the support point B from the force diagram for the beam and person:

$·\tau_B = - W(!L - d_2) + wx + F_A D = 0$;

$- (600 \text{ N})[!(20.0 \text{ m}) - 5.0 \text{ m}] + (600 \text{ N})(2.0 \text{ m}) + F_A(12.0 \text{ m}) = 0$,

which gives $F_A = 150$ N.

We write $·\tau = I\alpha$ about the support point A from the force diagram for the beam and person:

$·\tau_A = + W(!L - d_1) + w(D + x) - F_B D = 0$;

$+ (600 \text{ N})[!(20.0 \text{ m}) - 3.0 \text{ m}] + (600 \text{ N})(12.0 \text{ m} + 2.0 \text{ m}) - F_B(12.0 \text{ m}) = 0$,

which gives $F_B = 1050$ N.

(*d*) We write $·\tau = I\alpha$ about the support point B from the force diagram for the beam and person:

$·\tau_B = - W(!L - d_2) + wx + F_A D = 0$;

$- (600 \text{ N})[!(20.0 \text{ m}) - 5.0 \text{ m}] + (600 \text{ N})(- 2.0 \text{ m}) + F_A(12.0 \text{ m}) = 0$,

which gives $F_A = 750$ N.

We write $·\tau = I\alpha$ about the support point A from the force diagram for the beam and person:

$·\tau_A = + W(!L - d_1) + w(D + x) - F_B D = 0$;

$+ (600 \text{ N})[!(20.0 \text{ m}) - 3.0 \text{ m}] + (600 \text{ N})(12.0 \text{ m} - 2.0 \text{ m}) - F_B(12.0 \text{ m}) = 0$,

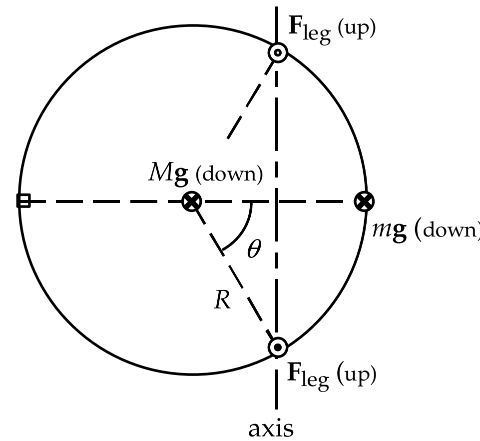
which gives $F_B = 450$ N.

73. The minimum mass is placed symmetrically between two of the legs of the table, so the normal force on the opposite leg becomes zero, as shown in the top view of the table. We write $\cdot\tau = I\alpha$ about a horizontal axis that passes through the two legs where there is a normal force:

$\cdot\tau = -MgR\cos\theta + mgR(1 - \cos\theta) = 0;$

$-(36\text{ kg})\cos 60° + m(1 - \cos 60°) = 0,$

which gives $m =$ 36 kg.



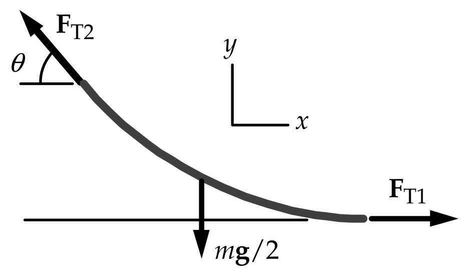
74. We select one-half of the cable for our system. From the force diagram for the section we can write

$\cdot F_x = F_{T1} - F_{T2}\cos\theta = 0;$

$F_{T1} - F_{T2}\cos 60° = 0.$

$\cdot F_y = +F_{T2}\sin\theta - !mg = 0;$

$F_{T2}\sin 60° - !mg = 0.$



When we combine these equations, we get

(*a*) $F_{T1} = mg/(2\tan 60°) =$ $0.289mg$;

(*b*) $F_{T2} = mg/(2\sin 60°) =$ $0.577mg$.

(c) The direction of the tension in each case is tangent to the cable:
horizontal at the lowest point, and 60° above the horizontal at the attachment.

75. Because there is no net horizontal force on the tower, from the force diagram for the tower we can write

$\cdot F_x = F_{T2}\sin\theta_2 - F_{T3}\sin\theta_3 = 0,$ or

$F_{T3} = F_{T2}(\sin\theta_2)/(\sin\theta_3).$

From the force diagram for the north span we can write

$\cdot F_x = F_{T1}\cos\theta_1 - F_{T2}\sin\theta_2 = 0,$ or

$F_{T1} = F_{T2}(\sin\theta_2)/(\cos\theta_1).$

$\cdot F_y = +F_{T2}\cos\theta_2 - F_{T1}\sin\theta_1 - mg$

$= 0,$ or

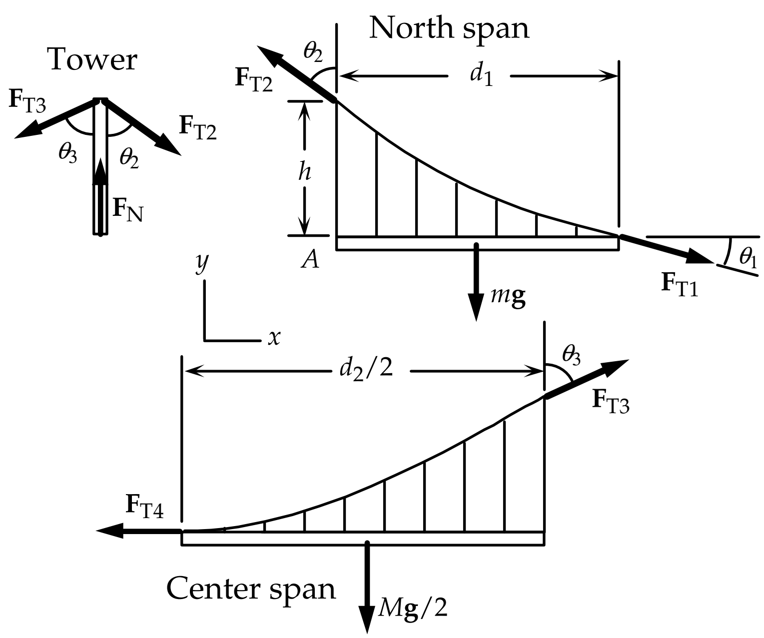
$mg = F_{T2}\cos\theta_2 - F_{T1}\sin\theta_1.$

From the force diagram for one-half of the center span we can write

$\cdot F_y = +F_{T3}\cos\theta_3 - !Mg = 0,$ or

$Mg = 2F_{T3}\cos\theta_3.$

Because the roadway is uniform, the length of each roadway is proportional to the mass:



$d_2/d_1 = M/m = (2F_{T3}\cos\theta_3)/(F_{T2}\cos\theta_2 - F_{T1}\sin\theta_1)$

$= 2[F_{T2}(\sin\theta_2)/(\sin\theta_3)](\cos\theta_3)/\{F_{T2}\cos\theta_2 - [F_{T2}(\sin\theta_2)/(\cos\theta_1)](\sin\theta_1)\}$

$= 2(\cot \theta_3)/(\cot \theta_2 - \tan \theta_1)$
$= 2(\cot 66°)/(\cot 60° - \tan 19°) =$ 3.8.

76. We choose the coordinate system shown, with positive torques clockwise.

(*a*) We write $\cdot F_x = ma_x$ from the force diagram:

$F_{Gx} - F_W = 0$, or $F_{Gx} = F_W$.

We write $\cdot F_y = ma_y$ from the force diagram:

$F_{Gy} - mg = 0$, which gives

$F_{Gy} = mg = (15.0\text{ kg})(9.80\text{ m/s}^2) = 147\text{ N}$.

We write $\cdot \tau = I\alpha$ about the point A from the force diagram for the ladder:

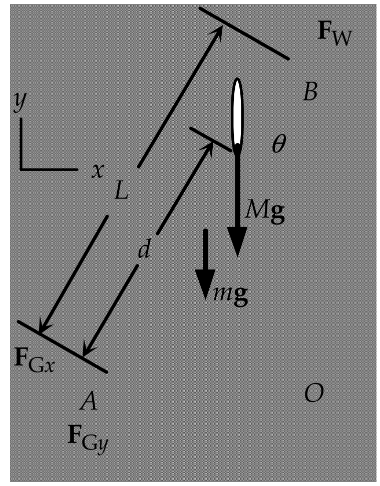
$\cdot \tau_A = mg(!L \sin \theta) - F_W L \cos \theta = 0$;

$(15.0\text{ kg})(9.80\text{ m/s}^2)!(\sin 20°) - F_W(\cos 20°) = 0$,

which gives $F_W = 27$ N.

Thus the components of the force at the ground are

$F_{Gx} = 27\text{ N}, F_{Gy} = 147\text{ N}$.



(*b*) We write $\cdot F_x = ma_x$ from the force diagram:

$F_{Gx} - F_W = 0$, or $F_{Gx} = F_W$.

We write $\cdot F_y = ma_y$ from the force diagram:

$F_{Gy} - mg - Mg = 0$, which gives $F_{Gy} = (m + M)g = (15.0\text{ kg} + 70\text{ kg})(9.80\text{ m/s}^2) = 833\text{ N}$.

We write $\cdot \tau = I\alpha$ about the point A from the force diagram for the ladder and person:

$\cdot \tau_A = mg(!L \sin \theta) + Mg(d \sin \theta) - F_W L \cos \theta = 0$;

$(15.0\text{ kg})(9.80\text{ m/s}^2)!(7.0\text{ m})(\sin 20°) + (70\text{ kg})(9.80\text{ m/s}^2)+(7.0\text{ m})(\sin 20°) - F_W(7.0\text{ m})(\cos 20°) = 0$,

which gives $F_W = 214\text{ N} = F_{Gx}$.

Because the ladder is on the verge of slipping, we must have

$F_{Gx} = \mu F_{Gy}$, or $\mu = F_{Gx}/F_{Gy} = (214\text{ N})/(833\text{ N}) =$ 0.26.

77. We have the same results from $\cdot \mathbf{F} = m\mathbf{a}$:

$F_{Gx} = F_W$; $F_{Gy} = (m + M)g = 833$ N.

Because the ladder is on the verge of slipping, we must have

$F_{Gx} = \mu F_{Gy} = (0.30)(833\text{ N}) = 250\text{ N} = F_W$.

We write $\cdot \tau = I\alpha$ about the point A from the force diagram for the ladder and person:

$\cdot \tau_A = mg(!L \sin \theta) + Mg(d \sin \theta) - F_W L \cos \theta = 0$;

$(15.0\text{ kg})(9.80\text{ m/s}^2)!(7.0\text{ m})(\sin 20°) + (70\text{ kg})(9.80\text{ m/s}^2)d(\sin 20°) - (250\text{ N})(7.0\text{ m})(\cos 20°) = 0$,

which gives $d =$ 6.3 m.

78. The maximum stress in a column will be at the bottom, caused by the weight of the material. If the column has density ρ, height h, and area A, we have

Stress $= F/A = mg/A = \rho Vg/A = \rho Ahg/A = \rho gh$, which is independent of area.

The column will buckle when this stress exceeds the compressive strength:

$h_{max} = (\text{Compressive strength})/\rho g$.

(*a*) For steel we have

$h_{max} = (500 \times 10^6\text{ N/m}^2)/(7.8 \times 10^3\text{ kg/m}^3)(9.80\text{ m/s}^2) =$ 6.5×10^3 m.

(*b*) For granite we have

$h_{max} = (170 \times 10^6\text{ N/m}^2)/(2.7 \times 10^3\text{ kg/m}^3)(9.80\text{ m/s}^2) =$ 6.4×10^3 m.

79. We assume when the brick strikes the floor there is an average force which produces an average stress in the brick, creating an average strain:

$ÆL/L_0 = (F/A)/E.$

If we use this average strain for the distance the CM moves while the brick comes to rest, the work done by the average force is $-F\,ÆL$. When we use the work-energy principle from the release point to the final resting point, we have

$-F\,ÆL = ÆKE + ÆPE = 0 + (0 - mgh)$, or

$h = F\,ÆL/mg = F(F/A)L_0/Emg = A(F/A)^2L_0/Emg.$

If we assume that the stress varies linearly from zero at the top of the brick to maximum at the bottom, the brick will break when the average stress exceeds one-half the compressive strength, so we have

$h_{min} = (0.15\text{ m})(0.060\text{ m})[!(35 \times 10^6\text{ N/m}^2)]^2(0.040\text{ m})/(14 \times 10^9\text{ N/m}^2)(1.2\text{ kg})(9.80\text{ m/s}^2) =$ 1.3 m.

80. We write $·F_x = ma_x$ from the force diagram:

$F - F_{fr} = 0$, or $F = F_{fr}$.

We write $·F_y = ma_y$ from the force diagram:

$F_N - Mg = 0$, or $F_N = Mg$.

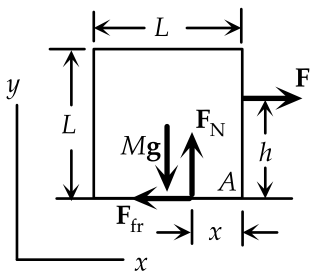
We find the location of the force F_N when the static friction force reaches its maximum value:

$F = F_{fr} = \mu_s F_N = \mu_s Mg.$

We write $·\tau = 0$ about the edge A of the block from the force diagram:

$·\tau_A = -Mg!L + F_N x - Fh = 0$, which gives

$x = (!MgL - Fh)/F_N = (!MgL - \mu_s Mgh)/Mg = !L - \mu_s h.$



(*a*) For the block to slide, we must have $x > 0$, or

$!L > \mu_s h$, which gives $\mu_s < L/2h$.

(*b*) For the block to tip, we must have $x < 0$, or

$!L < \mu_s h$, which gives $\mu_s > L/2h$.

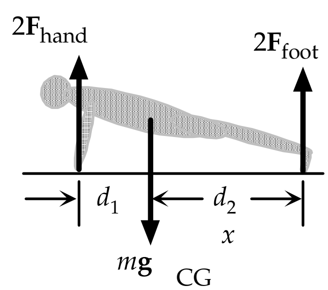
81. (*a*) We write $·\tau = 0$ about the feet from the force diagram:

$·\tau_{feet} = 2F_{hand}(d_1 + d_2) - mgd_2 = 0$, or

$F_{hand} = mgd_2/2(d_1 + d_2)$

$= (70\text{ kg})(9.80\text{ m/s}^2)(0.73\text{ m})/2(0.25\text{ m} + 0.73\text{ m})$

$=$ 2.6×10^2 N.



(*b*) We write $·\tau = 0$ about the hands from the force diagram:

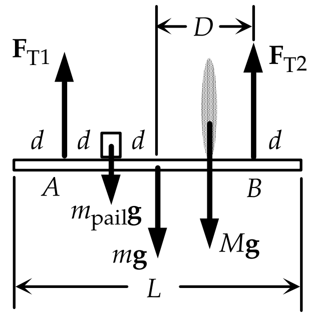
$·\tau_{hands} = -2F_{foot}(d_1 + d_2) + mgd_1 = 0$, or

$F_{foot} = mgd_1/2(d_1 + d_2)$

$= (70\text{ kg})(9.80\text{ m/s}^2)(0.25\text{ m})/2(0.25\text{ m} + 0.73\text{ m})$

$=$ 88 N.

82. The ropes can only provide a tension, so the scaffold will be stable if F_{T1} and F_{T2} are greater than zero. The tension will be least in the rope farthest from the painter. To find how far the painter can walk from the right rope toward the right end, we set $F_{T1} = 0$.



We write $\cdot\tau = 0$ about B from the force diagram:

$$\cdot\tau_B = Mgx_{right} + F_{T1}(D + 2d) - m_{pail}g(D + d) - mgD = 0;$$

$$(60\ kg)(9.80\ m/s^2)x_{right} + 0 - (4.0\ kg)(9.80\ m/s^2)(2.0\ m + 1.0\ m) - (25\ kg)(9.80\ m/s^2)(2.0\ m) = 0,$$

which gives $x_{right} = 1.03$ m.

Because this is greater than the distance to the end of the plank, 1.0 m, walking to the right end is safe.

To find how far the painter can walk from the right rope toward the right end, we set $F_{T2} = 0$.

We write $\cdot\tau = 0$ about A from the force diagram:

$$\cdot\tau_A = -Mgx_{left} - F_{T2}(D + 2d) + m_{pail}gd + mg2d = 0;$$

$$-(60\ kg)(9.80\ m/s^2)(1.0\ m) - 0 + (4.0\ kg)(9.80\ m/s^2)(1.0\ m) + (25\ kg)(9.80\ m/s^2)2(1.0\ m) = 0,$$

which gives $x_{left} = 0.90$ m.

Because this is less than the distance to the end of the plank, 1.0 m, walking to the left end is not safe.

The painter can safely walk to within 0.10 m of the left end.