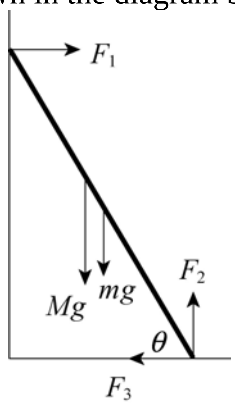
2. Our notation is as follows: M = 1360 kg is the mass of the automobile; L = 3.05 m is the horizontal distance between the axles; $\ell = (3.05 - 1.78)\text{ m} = 1.27\text{ m}$ is the horizontal distance from the rear axle to the center of mass; F_1 is the force exerted on each front wheel; and F_2 is the force exerted on each back wheel.

(a) Taking torques about the rear axle, we find

$$F_1 = \frac{Mg\ell}{2L} = \frac{(1360\text{ kg})(9.80\text{ m/s}^2)(1.27\text{ m})}{2(3.05\text{ m})} = 2.77\times10^3\text{ N}.$$

(b) Equilibrium of forces leads to $2F_1 + 2F_2 = Mg$, from which we obtain $F_2 = 3.89\times10^3\text{ N}$.

7. The forces on the ladder are shown in the diagram below.



F_1 is the force of the window, horizontal because the window is frictionless. F_2 and F_3 are components of the force of the ground on the ladder. M is the mass of the window cleaner and m is the mass of the ladder.

The force of gravity on the man acts at a point 3.0 m up the ladder and the force of gravity on the ladder acts at the center of the ladder. Let θ be the angle between the ladder and the ground. We use $\cos\theta = d/L$ or $\sin\theta = \sqrt{L^2 - d^2}/L$ to find $\theta = 60^\circ$. Here L is the length of the ladder (5.0 m) and d is the distance from the wall to the foot of the ladder (2.5 m).

(a) Since the ladder is in equilibrium the sum of the torques about its foot (or any other point) vanishes. Let ℓ be the distance from the foot of the ladder to the position of the window cleaner. Then,

$$Mg\ell\cos\theta + mg\left(L/2\right)\cos\theta - F_1 L\sin\theta = 0,$$

and

$$F_1 = \frac{(M\ell + mL/2)g\cos\theta}{L\sin\theta} = \frac{[(75\text{ kg})(3.0\text{ m})+(10\text{ kg})(2.5\text{ m})](9.8\text{ m/s}^2)\cos 60^\circ}{(5.0\text{ m})\sin 60^\circ}$$

$$= 2.8\times10^2\text{ N}.$$

This force is outward, away from the wall. The force of the ladder on the window has the same magnitude but is in the opposite direction: it is approximately 280 N, inward.

(b) The sum of the horizontal forces and the sum of the vertical forces also vanish:

$$F_1 - F_3 = 0$$
$$F_2 - Mg - mg = 0$$

The first of these equations gives $F_3 = F_1 = 2.8\times10^2$ N and the second gives

$$F_2 = (M+m)g = (75\,\text{kg} + 10\,\text{kg})(9.8\,\text{m/s}^2) = 8.3\times10^2\,\text{N}\,.$$

The magnitude of the force of the ground on the ladder is given by the square root of the sum of the squares of its components:

$$F = \sqrt{F_2^{\,2} + F_3^{\,2}} = \sqrt{(2.8\times10^2\,\text{N})^2 + (8.3\times10^2\,\text{N})^2} = 8.8\times10^2\,\text{N}.$$

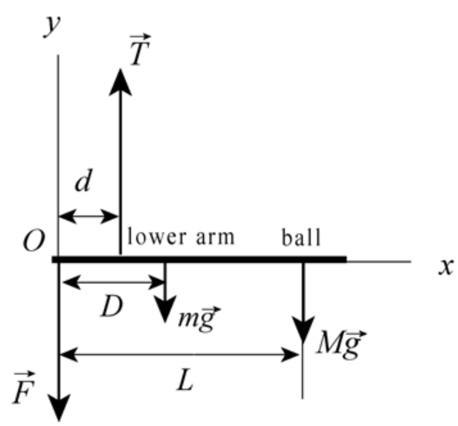
(c) The angle ϕ between the force and the horizontal is given by

$$\tan\phi = F_3/F_2 = (830\text{ N})/(280\text{ N}) = 2.94,$$

so $\phi = 71°$. The force points to the left and upward, 71° above the horizontal. We note that this force is not directed along the ladder.

20. Our system consists of the lower arm holding a bowling ball. As shown in the free-body diagram, the forces on the lower arm consist of $\vec{T}$ from the biceps muscle, $\vec{F}$ from the bone of the upper arm, and the gravitational forces, $m\vec{g}$ and $M\vec{g}$. Since the system is in static equilibrium, the net force acting on the system is zero:

$$0 = \sum F_{\text{net},y} = T - F - (m+M)g\,.$$



In addition, the net torque about O must also vanish:

$$0 = \sum_O \tau_{\text{net}} = (d)(T) + (0)F - (D)(mg) - L(Mg)\,.$$

(a) From the torque equation, we find the force on the lower arms by the biceps muscle to be

$$T = \frac{(mD + ML)g}{d} = \frac{[(1.8\text{ kg})(0.15\text{ m}) + (7.2\text{ kg})(0.33\text{ m})](9.8\text{ m/s}^2)}{0.040\text{ m}}$$
$$= 648\text{ N} \approx 6.5\times10^2\text{ N}.$$

(b) Substituting the above result into the force equation, we find F to be

$$F = T - (M + m)g = 648\text{ N} - (7.2\text{ kg} + 1.8\text{ kg})(9.8\text{ m/s}^2) = 560\text{ N} = 5.6\times10^2\text{ N}.$$

23. The beam is in equilibrium: the sum of the forces and the sum of the torques acting on it each vanish. As shown in the figure, the beam makes an angle of 60º with the vertical and the wire makes an angle of 30º with the vertical.

(a) We calculate the torques around the hinge. Their sum is

$$TL\sin 30^\circ - W(L/2)\sin 60^\circ = 0.$$

Here W is the force of gravity acting at the center of the beam, and T is the tension force of the wire. We solve for the tension:

$$T = \frac{W\sin 60^\circ}{2\sin 30^\circ} = \frac{(222\text{N})\sin 60^\circ}{2\sin 30^\circ} = 192\text{ N}.$$

(b) Let F_h be the horizontal component of the force exerted by the hinge and take it to be positive if the force is outward from the wall. Then, the vanishing of the horizontal component of the net force on the beam yields $F_h - T\sin 30^\circ = 0$ or

$$F_h = T\sin 30^\circ = (192.3\text{ N})\sin 30^\circ = 96.1\text{ N}.$$

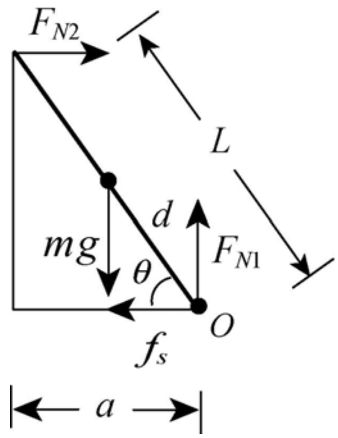
(c) Let F_v be the vertical component of the force exerted by the hinge and take it to be positive if it is upward. Then, the vanishing of the vertical component of the net force on the beam yields $F_v + T\cos 30^\circ - W = 0$ or

$$F_v = W - T\cos 30^\circ = 222\text{ N} - (192.3\text{ N})\cos 30^\circ = 55.5\text{ N}.$$

26. As shown in the free-body diagram, the forces on the climber consist of the normal forces F_{N1} on his hands from the ground and F_{N2} on his feet from the wall, static frictional force f_s, and downward gravitational force mg. Since the climber is in static equilibrium, the net force acting on him is zero.

Applying Newton's second law to the vertical and horizontal directions, we have

$$0=\sum F_{\text{net},x}=F_{N2}-f_s$$
$$0=\sum F_{\text{net},y}=F_{N1}-mg\ .$$



In addition, the net torque about O (contact point between his feet and the wall) must also vanish:

$$0=\sum_O \tau_{\text{net}}=mgd\cos\theta-F_{N2}L\sin\theta\ .$$

The torque equation gives

$$F_{N2}=mgd\cos\theta/L\sin\theta=mgd\cot\theta/L\ .$$

On the other hand, from the force equation we have $F_{N2}=f_s$ and $F_{N1}=mg$. These expressions can be combined to yield

$$f_s=F_{N2}=F_{N1}\cot\theta\frac{d}{L}\ .$$

On the other hand, the frictional force can also be written as $f_s=\mu_s F_{N1}$, where μ_s is the coefficient of static friction between his feet and the ground. From the above equation and the values given in the problem statement, we find μ_s to be

$$\mu_s=\cot\theta\frac{d}{L}=\frac{a}{\sqrt{L^2-a^2}}\frac{d}{L}=\frac{0.914\text{ m}}{\sqrt{(2.10\text{ m})^2-(0.914\text{ m})^2}}\frac{0.940\text{ m}}{2.10\text{ m}}=0.216\ .$$