# Chapter 6

1. The greatest deceleration (of magnitude $a$) is provided by the maximum friction force (Eq. 6-1, with $F_N = mg$ in this case). Using Newton's second law, we find

$$a = f_{s,\max}/m = \mu_s g.$$

Equation 2-16 then gives the shortest distance to stop: $|\Delta x| = v^2/2a = 36$ m. In this calculation, it is important to first convert $v$ to 13 m/s.

5. In addition to the forces already shown in Fig. 6-17, a free-body diagram would include an upward normal force $\vec{F}_N$ exerted by the floor on the block, a downward $m\vec{g}$ representing the gravitational pull exerted by Earth, and an assumed-leftward $\vec{f}$ for the kinetic or static friction. We choose $+x$ rightward and $+y$ upward. We apply Newton's second law to these axes:

$$F - f = ma$$
$$P + F_N - mg = 0$$

where $F = 6.0$ N and $m = 2.5$ kg is the mass of the block.

(a) In this case, $P = 8.0$ N leads to

$$F_N = (2.5\text{ kg})(9.8\text{ m/s}^2) - 8.0\text{ N} = 16.5\text{ N}.$$

Using Eq. 6-1, this implies $f_{s,\max} = \mu_s F_N = 6.6$ N, which is larger than the 6.0 N rightward force. Thus, the block (which was initially at rest) does not move. Putting $a = 0$ into the first of our equations above yields a static friction force of $f = P = 6.0$ N.

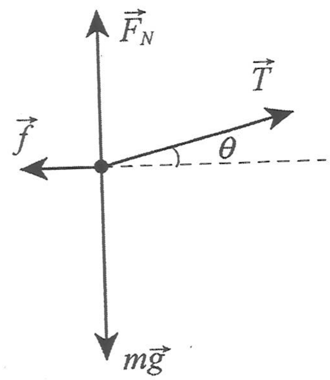
(b) In this case, $P = 10$ N, the normal force is

$$F_N = (2.5\text{ kg})(9.8\text{ m/s}^2) - 10\text{ N} = 14.5\text{ N}.$$

Using Eq. 6-1, this implies $f_{s,\max} = \mu_s F_N = 5.8$ N, which is less than the 6.0 N rightward force – so the block does move. Hence, we are dealing not with static but with kinetic friction, which Eq. 6-2 reveals to be $f_k = \mu_k F_N = 3.6$ N.

(c) In this last case, $P = 12$ N leads to $F_N = 12.5$ N and thus to $f_{s,\max} = \mu_s F_N = 5.0$ N, which (as expected) is less than the 6.0 N rightward force. Thus, the block moves. The kinetic friction force, then, is $f_k = \mu_k F_N = 3.1$ N.

11. (a) The free-body diagram for the crate is shown below.




$\vec{T}$ is the tension force of the rope on the crate, $\vec{F}_N$ is the normal force of the floor on the crate, $m\vec{g}$ is the force of gravity, and $\vec{f}$ is the force of friction. We take the $+x$ direction to be horizontal to the right and the $+y$ direction to be up. We assume the crate is motionless. The equations for the $x$ and the $y$ components of the force according to Newton's second law are:

$$T\cos\theta - f = 0$$
$$T\sin\theta + F_N - mg = 0$$

where $\theta = 15°$ is the angle between the rope and the horizontal. The first equation gives $f = T\cos\theta$ and the second gives $F_N = mg - T\sin\theta$. If the crate is to remain at rest, $f$ must be less than $\mu_s F_N$, or $T\cos\theta < \mu_s(mg - T\sin\theta)$. When the tension force is sufficient to just start the crate moving, we must have

$$T\cos\theta = \mu_s(mg - T\sin\theta).$$

We solve for the tension:

$$T = \frac{\mu_s mg}{\cos\theta + \mu_s\sin\theta} = \frac{(0.50)\,(68\text{ kg})\,(9.8\text{ m/s}^2)}{\cos 15° + 0.50\sin 15°} = 304\text{ N} \approx 3.0\times10^2\text{ N}.$$

(b) The second law equations for the moving crate are

$$T\cos\theta - f = ma$$
$$F_N + T\sin\theta - mg = 0.$$

Now $f = \mu_k F_N$, and the second equation gives $F_N = mg - T\sin\theta$, which yields $f = \mu_k(mg - T\sin\theta)$. This expression is substituted for $f$ in the first equation to obtain

$$T\cos\theta - \mu_k(mg - T\sin\theta) = ma,$$

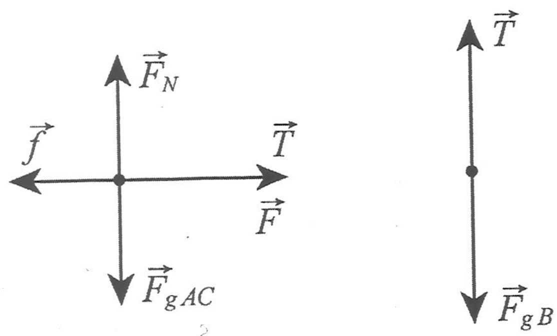
so the acceleration is

$$a = \frac{T(\cos\theta + \mu_k\sin\theta)}{m} - \mu_k g.$$

Numerically, it is given by

$$a = \frac{(304\text{ N})(\cos 15° + 0.35\sin 15°)}{68\text{ kg}} - (0.35)(9.8\text{ m/s}^2) = 1.3\text{ m/s}^2.$$

29. (a) Free-body diagrams for the blocks $A$ and $C$, considered as a single object, and for the block $B$ are shown below.




$T$ is the magnitude of the tension force of the rope, $F_N$ is the magnitude of the normal force of the table on block $A$, $f$ is the magnitude of the force of friction, $W_{AC}$ is the combined weight of blocks $A$ and $C$ (the magnitude of force $\vec{F}_{g\,AC}$ shown in the figure), and $W_B$ is the weight of block $B$ (the magnitude of force $\vec{F}_{g\,B}$ shown). Assume the blocks are not moving. For the blocks on the table we take the $x$ axis to be to the right and the $y$ axis to be upward. From Newton's second law, we have

$$x \text{ component:} \quad T - f = 0$$

$$y \text{ component:} \quad F_N - W_{AC} = 0.$$

For block $B$ take the downward direction to be positive. Then Newton's second law for that block is $W_B - T = 0$. The third equation gives $T = W_B$ and the first gives $f = T = W_B$. The second equation gives $F_N = W_{AC}$. If sliding is not to occur, $f$ must be less than $\mu_s F_N$, or $W_B < \mu_s W_{AC}$. The smallest that $W_{AC}$ can be with the blocks still at rest is

$$W_{AC} = W_B/\mu_s = (22 \text{ N})/(0.20) = 110 \text{ N}.$$

Since the weight of block $A$ is 44 N, the least weight for $C$ is $(110 - 44)$ N = 66 N.

(b) The second law equations become

$$T - f = (W_A/g)a$$
$$F_N - W_A = 0$$
$$W_B - T = (W_B/g)a.$$

In addition, $f = \mu_k F_N$. The second equation gives $F_N = W_A$, so $f = \mu_k W_A$. The third gives $T = W_B - (W_B/g)a$. Substituting these two expressions into the first equation, we obtain

$$W_B - (W_B/g)a - \mu_k W_A = (W_A/g)a.$$

Therefore,

$$a = \frac{g(W_B - \mu_k W_A)}{W_A + W_B} = \frac{(9.8 \text{ m/s}^2)(22 \text{ N} - (0.15)(44 \text{ N}))}{44 \text{ N} + 22 \text{ N}} = 2.3 \text{ m/s}^2.$$

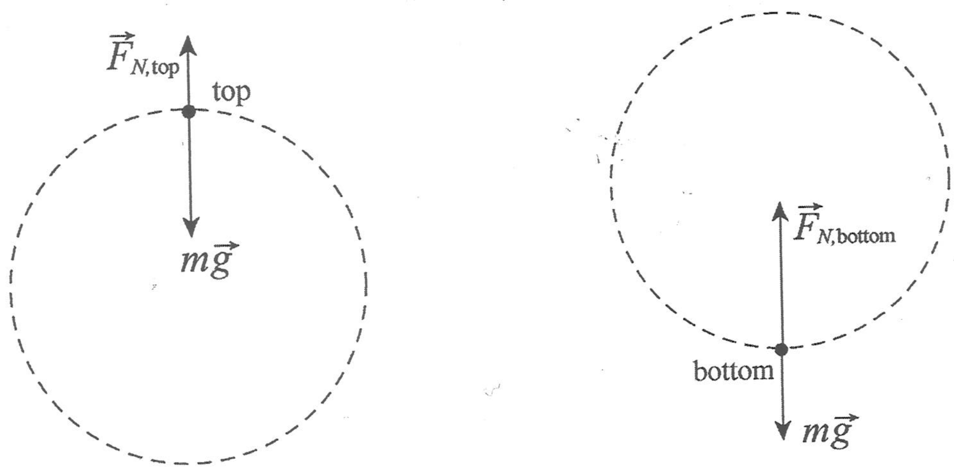
shown below. At the top (the highest point in the circular motion) the seat pushes up on the student with a force of magnitude $F_{N,\text{top}}$, while the Earth pulls down with a force of magnitude $mg$. Newton's second law for the radial direction gives

$$mg - F_{N,\text{top}} = \frac{mv^2}{R}.$$

At the bottom of the ride, $F_{N,\text{bottom}}$ is the magnitude of the upward force exerted by the seat. The net force toward the center of the circle is (choosing upward as the positive direction):

$$F_{N,\text{bottom}} - mg = \frac{mv^2}{R}.$$

The Ferris wheel is "steadily rotating" so the value $F_c = mv^2/R$ is the same everywhere. The apparent weight of the student is given by $F_N$.




(a) At the top, we are told that $F_{N,\text{top}} = 556$ N and $mg = 667$ N. This means that the seat is pushing up with a force that is smaller than the student's weight, and we say the student experiences a decrease in his "apparent weight" at the highest point. Thus, he feels "light."

(b) From (a), we find the centripetal force to be

$$F_c = \frac{mv^2}{R} = mg - F_{N,\text{top}} = 667\text{ N} - 556\text{ N} = 111\text{ N}.$$

Thus, the normal force at the bottom is

$$F_{N,\text{bottom}} = \frac{mv^2}{R} + mg = F_c + mg = 111\text{ N} + 667\text{ N} = 778\text{ N}.$$

(c) If the speed is doubled, $F_c' = \dfrac{m(2v)^2}{R} = 4(111\text{ N}) = 444\text{ N}$. Therefore, at the highest point we have

$$F'_{N,\text{top}} = mg - F_c' = 667\text{ N} - 444\text{ N} = 223\text{ N}.$$

(d) Similarly, the normal force at the lowest point is now found to be

$$F'_{N,\text{bottom}} = F_c' + mg = 444\text{ N} + 667\text{ N} = 1111\text{ N} \approx 1.11\times10^3\text{ N}.$$

Note: The apparent weight of the student is the greatest at the bottom and smallest at the top of the ride. The speed $v = \sqrt{gR}$ would result in $F_{N,\text{top}} = 0$, giving the student a sudden sensation of "weightlessness" at the top of the ride.

70. (a) We note that $R$ (the horizontal distance from the bob to the axis of rotation) is the circumference of the circular path divided by $2\pi$; therefore, $R = 0.94/2\pi = 0.15$ m. The angle that the cord makes with the horizontal is now easily found:

$$\theta = \cos^{-1}(R/L) = \cos^{-1}(0.15 \text{ m}/0.90 \text{ m}) = 80^\circ.$$

The vertical component of the force of tension in the string is $T\sin\theta$ and must equal the downward pull of gravity ($mg$). Thus,

$$T = \frac{mg}{\sin\theta} = 0.40 \text{ N}.$$

Note that we are using $T$ for tension (not for the period).

(b) The horizontal component of that tension must supply the centripetal force (Eq. 6-18), so we have $T\cos\theta = mv^2/R$. This gives speed $v = 0.49$ m/s. This divided into the circumference gives the time for one revolution: $0.94/0.49 = 1.9$ s.