Q4. In three experiments, three different horizontal forces are applied to the same block lying on the same countertop. The force magnitudes are \( F_1 = 12 \text{ N} \), \( F_2 = 8 \text{ N} \), and \( F_3 = 4 \text{ N} \). In each experiment, the block remains stationary in spite of the applied force. Rank the forces according to (a) the magnitude \( f_s \) of the static frictional force on the block from the countertop and (b) the maximum value \( f_{s,\text{max}} \) of that force, greatest first.

(a) \( f_s \) for \( F_1 \) > \( f_s \) for \( F_2 \) > \( f_s \) for \( F_3 \).

In each case, \( f_s \) has the same magnitude as the applied force. We know this because \( \vec{a} = 0 \), so \( F_{\text{NET}} = 0 \).

(b) \( f_{s,\text{max}} \) is equal in all cases. We only know it’s greater than 12 N.

Q6. In Fig. 6-14, a block of mass \( m \) is held stationary on a ramp by the frictional force on it from the ramp. A force \( \vec{F} \), directed up the ramp, is then applied to the block and gradually increased in magnitude from zero. During the increase, what happens to the direction and magnitude of the frictional force on the block?

Initially, \( f_s \) is up-ramp. As \( F \) increases, \( f_s \) decreases, and reaches zero when \( F = mg \sin \theta \). As \( F \) is further increased, \( f_s \) becomes down-ramp, until \( F \) is strong enough to break static friction and slide the block up-ramp.

Q10. In 1987, as a Halloween stunt, two sky divers passed a pumpkin back and forth between them while they were in free fall just west of Chicago. The stunt was great fun until the last sky diver with the pumpkin opened his parachute. The pumpkin broke free from his grip, plummeted about 0.5 km, ripped through the roof of a house, slammed into the kitchen floor, and splattered all over the newly remodeled kitchen. From the sky diver’s viewpoint and from the pumpkin’s viewpoint, why did the sky diver lose control of the pumpkin?

From the sky diver’s point of view, he needed to accelerate (slow down, in this case) the pumpkin at the same rate his now-open chute accelerated him. FBD for pumpkin: \( F_N \) up; \( mg \) down; \( \vec{a} \) up and large, if the skydiver is to keep the pumpkin with him. Here, \( F_N \) is the normal (support) force by the skydiver on the pumpkin. Depending on his grip, this might be \( f_s \). In any case, the force the skydiver needed to exert on the pumpkin to give it a large acceleration exceeded what he could exert.

From the pumpkin’s point of view, it tended to remain is its velocity (fast downward) and the skydiver didn’t exert enough force on it to change this velocity to (slow downward) in the time the chute slowed the sky diver.

Newton’s Second Law \( \vec{F}_{\text{NET}} = m\vec{a} \) is to be understood. Reference to the “x-eq” and “y-eq” are the \( x \)- and \( y \)-components of this equation.

P1. The floor of a railroad flatcar is loaded with loose crates having a coefficient of static friction of 0.25 with the floor. If the train is initially moving at a speed of 48 km/h, in how short a distance can the train be stopped at constant acceleration without causing the crates to slide over the floor?

Recognize that we need the acceleration to calculate the distance, and that we first need Newton’s 2nd Law to calculate the acceleration. Note that 48 km/hr = 13.33 m/s.

The crates are moving to the right, along with the train.

FBD for one crate: \( mg \) down; \( n \) up; \( f_s \) (static!) to the left. \( \vec{a} \) to the left. Since the train is slowing, \( \vec{a} \) is in the opposite direction of \( \vec{v} \); hence \( \vec{a} \) is to the left, and so is the one unbalanced force, \( f_s \). Make \( +x \) to the right, so that \( v_{0x} \) is positive. This means that \( a_x \) will be negative; and yes, this is the opposite of my usual practice to make \( +x \) in the direction of acceleration.

\( y \)-eq: \( n - mg = 0 \) \( \Rightarrow \) \( n = mg \). The mass of this crate is \( m \).

\( x \)-eq: \(-f_s = ma_x \). At the limit of static friction, \( f_s = \mu_s n = \mu_s mg \).
\[ a_x = (-\mu_s mg)/m = -\mu_s g = -2.45 \text{ m/s}^2. \]
\[ \Delta x = (v_f^2 - v_0^2)/2a = (0 - (13.33\text{ m/s})^2)/(2 \cdot (-2.45 \text{ m/s}^2)) = 36.3 \text{ m}. \]

We note that the answer didn’t depend on the mass of the crate, so the answer is the same for all the other crates.

**P2.** In a pickup game of dorm shuffleboard, students crazed by final exams use a broom to propel a calculus book along the dorm hallway. If the 3.5 kg book is pushed from rest through a distance of 0.90 m by the horizontal 25 N force from the broom and then has a speed of 1.60 m/s, what is the coefficient of kinetic friction between the book and floor?

Strategy: calculate acceleration from the given distance and final velocity; then use Newton’s 2nd Law to determine what \( f_k \) was necessary; then plug \( \mu_k = f_k/n \) to get the coefficient.

\[ a_x = (v_f^2 - v_0^2)/2\Delta x = 1.6^2/(2 \cdot 0.90) = 1.422 \text{ m/s}^2. \]
FBD for book: \( mg \) down; \( n \) up; \( F_p \) to right; \( f_k \) to left. \( \vec{a} \) to right. Make +x to right.

\[ y\text{-eq: } n - mg = 0 \Rightarrow n = mg = (3.5 \text{ kg})(9.8 \text{ m/s}^2) = 34.30 \text{ N}. \]
\[ x\text{-eq: } F_p - f_k = ma_x \Rightarrow f_k = F_p - ma_x = 20.02 \text{ N}. \]
\[ \mu_k = f_k/n = 20.02/34.30 = 0.583. \]

**P4.** A slide-loving pig slides down a certain 35° slide in twice the time it would take to slide down a frictionless 35° slide. What is the coefficient of kinetic friction between the pig and the slide?

First, determine what the time ratio means in terms of accelerations. Then use Newton’s Second Law to get forces and solve for \( \mu_k \). Let \( L \) be the length of the slide, which should not enter the answer.

\[ L = (1/2)a_1t_1^2 \text{ and } L = (1/2)a_2t_2^2. \]
\[ a_1t_1^2 = a_2t_2^2 \Rightarrow a_1/a_2 = t_2^2/t_1^2 = (1/2)^2 = 1/4. \]
In other words, \( a_1 = (1/4)a_2 \).

FBD for pig: \( mg \) down; \( n \) away from slide; \( f_k \) up-slide. \( \vec{a} \) is down-slide. +x down-slide, +y away from slide. Solve the with-friction problem, and have the frictionless problem by setting \( \mu_k = 0 \).

\[ y\text{-eq: } n - mg \cos \theta = 0 \Rightarrow n = mg \cos \theta. \]
\[ \theta = 35^\circ; \text{ and } f_k = \mu_k n = \mu_k mg \cos \theta. \]
\[ x\text{-eq: } mg \sin \theta - f_k = ma_x \Rightarrow mg \sin \theta - \mu_k mg \cos \theta = ma_x. \]
\[ a_x = g(\sin \theta - \mu_k \cos \theta). \]

Now, \( a_1 = a_x \) and \( a_2 = A_x|_{\mu_k=0} \). Substitute.

\[ g(\sin \theta - \mu_k \cos \theta) = (1/4)g \sin \theta \Rightarrow \]
\[ \mu_k = (3/4) \tan \theta = (0.75)/(0.7002) = 0.525. \]

**P13.** A worker pushes horizontally on a 35 kg crate with a force of magnitude 110 N. The coefficient of static friction between the crate and the floor is 0.37. (a) What is the value of \( f_{s,\text{max}} \) under the circumstances? (b) Does the crate move? (c) What is the frictional force on the crate from the floor? (d) Suppose, next, that a second worker pulls directly upward on the crate to help out. What is the least vertical pull that will allow the first worker’s 110 N push to move the crate? (e) If, instead, the second worker pulls horizontally to help out, what is the least pull that will get the crate moving?

(a) FBD for crate: \( mg \) down; \( n \) up; \( F_0 \) to right; \( f_s \) to left. \( \vec{a} = 0 \). +x to right. \( F_0 \) is a generic horizontal applied force.

\[ y\text{-eq: } n - mg = 0 \Rightarrow n = mg. \text{ We need } n \text{ to answer part (a).} \]
\[ f_{s,\text{max}} = \mu_s n = \mu_s mg = (0.37)(35 \text{ kg})(9.8 \text{ m/s}^2) = 127 \text{ N}. \]

(b) No. Explanation in next part.

(c) \( f_s = 110 \text{ N}, \text{ to the left.} \) The static frictional force \( f_s \) automatically adjusts itself to make \( \vec{a} = 0 \), until the net of other forces reaches \( f_{s,\text{max}} \).

(d) FBD: same as part (a), except add \( F_2 \) upward.
New y-eq: \( n + F_2 - mg = 0 \implies n = mg - F_2 \). The new \( f_{s,\text{max}} \) has to be 110 N for the crate to move, so

\[
f_{s,\text{max}} = \mu_s (mg - F_2) = 110 \text{ N} \implies F_2 = (\mu_s mg - 110 \text{ N})/\mu_s = 45.7 \text{ N}
\]

(e) FBD: same as part (a), except add \( F_3 \) to the right.

New x-eq: \( F_3 + F_1 - f_s = 0 \). Here, \( f_s \) is set to \( f_{s,\text{max}} \), and \( F_3 \) is increased by some arbitrarily small amount so that \( \vec{a} \) is some arbitrarily small value to the right. At this point, \( f_s \) gets replaced in the x-eq by \( f_k \), and the acceleration is some reasonable value.

\[
F_3 = f_{s,\text{max}} - F_1 = 126.9 \text{ N} - 110 \text{ N} = 16.9 \text{ N}.
\]

P16. A loaded penguin sled weighing 80 N rests on a plane inclined at angle \( \theta = 20^\circ \) to the horizontal (Fig. 6-23). Between the sled and the plane, the coefficient of static friction is 0.25, and the coefficient of kinetic friction is 0.15. (a) What is the least magnitude of the force parallel to the plane, that will prevent the sled from slipping down the plane? (b) What is the minimum magnitude \( F \) that will start the sled moving up the plane? (c) What value of \( F \) is required to move the sled up the plane at constant velocity?

(a) FBD for sled: \( mg \) down; \( n \) away from plane; \( F \) up-plane; \( f_s \) up-plane. Note the direction of \( f_s \): the sled is at the point of sliding down-plane, so \( f_s \) opposes this. \( \vec{a} = 0 \). Make \( +x \) up-plane (down-plane is also reasonable).

y-eq: \( n - mg \cos \theta = 0 \implies n = mg \cos \theta \).

x-eq: \( F + f_s - mg \sin \theta = 0 \). Set \( f_s = f_{s,\text{max}} = \mu_s n = \mu_s mg \cos \theta \). Then solve for \( F \):

\[
F = mg (\sin \theta - \mu_s \cos \theta) = (80 \text{ N})(0.3430 - 0.25 \cdot 0.9397) = 8.57 \text{ N}.
\]

(b) FBD: same as part (a), except \( f_s \) is down-slope. The y-eq is the same, and the only modification to the x-eq is to reverse the sign on \( f_s \):

\[
F - f_s - mg \sin \theta = 0 \text{. As before, set } f_s = f_{s,\text{max}} = \mu_s n = \mu_s mg \cos \theta \text{. Solve for } F:
F = mg (\sin \theta + \mu_s \cos \theta) = (80 \text{ N})(0.3430 + 0.25 \cdot 0.9397) = 46.1 \text{ N}.
\]

(c) FBD: same as in (b), except that \( f_s \) is replaced by \( f_k = \mu_k n = \mu_k mg \cos \theta \). The y-eq is changed by substituting \( \mu_k \) for \( \mu_s \). Note that \( \vec{a} = 0 \) still applies: velocity is constant.

\[
F - f_k - mg \sin \theta = 0 \text{. Set } f_k = \mu_k mg \cos \theta \text{. Solve for } F:
F = mg (\sin \theta + \mu_k \cos \theta) = (80 \text{ N})(0.3430 + 0.15 \cdot 0.9397) = 38.6 \text{ N}.
\]