

## 2.2.2 In Class or Homework Exercise

1. A sled of mass  $50.0\text{ kg}$  is pulled along snow-covered, flat ground. The static friction coefficient is  $0.30$ , and the sliding coefficient is  $0.10$ .

(a) What force is needed to start the sled moving?

In order to start the sled moving, the force of the push must be greater than the force of friction ( $F_p > F_f$ ). Since the sled is not yet moving, this is a static situation.

$$\mu_s = 0.30$$

$$m = 50.0\text{kg}$$

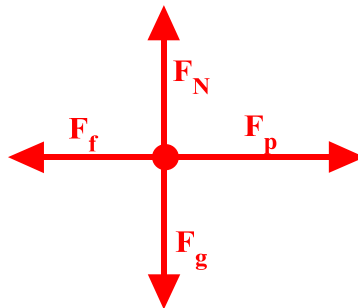
$$g = 9.80\text{m/s}^2$$

$$F_p = ?$$

$$F_g = mg$$

$$= (50.0)(9.80)$$

$$= 490.\text{N}$$



$$F_f = \mu_s F_N$$

$$= \mu_s F_g$$

$$= (0.30)(490.)$$

$$= 147\text{N}$$

so

$$F_p > 147\text{N}$$

(b) What force is needed to keep the sled moving at constant velocity?

In order to keep the sled moving at constant velocity, the force of the push must be equal to the force of friction ( $F_p = F_f$ ). Since the sled is moving, this is a kinetic situation.

$$\mu_k = 0.10$$

$$m = 50.0\text{kg}$$

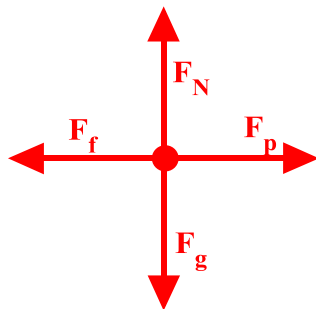
$$g = 9.80\text{m/s}^2$$

$$F_p = ?$$

$$F_g = mg$$

$$= (50.0)(9.80)$$

$$= 490.\text{N}$$

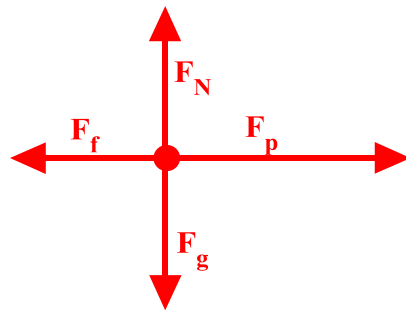


$$\begin{aligned}
 F_f &= \mu_k F_N \\
 &= \mu_k F_g \\
 &= (0.10)(490.) \\
 &= 49N
 \end{aligned}
 \quad \text{so} \quad \boxed{F_p = 49N}$$

- (c) Once moving, what force must be applied to the sled to accelerate it at  $3.00 \text{ m/s}^2$ ?

In order to keep the accelerate the sled, the force of the push must be greater than the force of friction ( $F_p > F_f$ ); however, since we have an acceleration, we are able to calculate the specific force required. Since the sled is moving, this is a kinetic situation.

$$\begin{aligned}
 F_f &= 49N \\
 F_g &= 490.N \\
 a &= 3.00\text{m} / \text{s}^2 \\
 m &= 50.0\text{kg} \\
 F_p &= ?
 \end{aligned}$$



Applying Newton's Second Law,

$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_p + \vec{F}_f \\
 (50.0)(3.00) &= F_p - 49 \\
 F_p &= \boxed{199N}
 \end{aligned}$$

2. A  $65 \text{ kg}$  swimmer jumps off a  $10.0 \text{ m}$  tower. Assume the swimmer's initial velocity is zero.

- (a) Find the swimmer's velocity when hitting the water.

Since the swimmer is in free fall, their downward acceleration is  $9.80 \text{ m/s}^2$ . Using down as positive,

$$\begin{aligned}
 a &= 9.80 \text{ m/s}^2 & \Delta \vec{d} &= \frac{v_f^2 - v_i^2}{2\vec{a}} \\
 \vec{v}_i &= 0 & 10.0 &= \frac{v_f^2 - 0}{2(9.80)} \\
 \Delta \vec{d} &= 10.0 \text{ m} & \vec{v}_f &= \boxed{14 \text{ m/s}} \\
 \vec{v}_f &=? & &
 \end{aligned}$$

- (b) The swimmer comes to a stop 2.0 m below the surface of the water. Find the average net force exerted on the swimmer over this 2.0 m. We must first find the acceleration of the swimmer in the water, We will continue to use down as positive.

$$\begin{aligned}
 m &= 65 \text{ kg} & \Delta \vec{d} &= \frac{v_f^2 - v_i^2}{2\vec{a}} \\
 \vec{v}_i &= 14 \text{ m/s} & 2.0 &= \frac{0 - 14^2}{2\vec{a}} \\
 \vec{v}_f &= 0 & \vec{a} &= -49 \text{ m/s}^2 \\
 \Delta \vec{d} &= 2.0 \text{ m} & & \\
 \vec{a} &=? & &
 \end{aligned}$$

We can not find the net force:

$$\begin{aligned}
 \vec{F}_{net} &= m\vec{a} \\
 &= (65)(-49) \\
 &= \boxed{-3200 \text{ N}}
 \end{aligned}$$

Notice that the negative sign tells us that the net force must be upward (in the same direction as the acceleration)

- (c) Find the force exerted by the water on the swimmer. Since we are now looking for an individual force, we must draw a free body diagram:

$$\begin{aligned}
 m &= 65 \text{ kg} & F_g &= mg \\
 g &= 9.80 \text{ m/s}^2 & &= (65)(9.80) \\
 \vec{a} &= -49 \text{ m/s}^2 & &= 637 \text{ N} \\
 F_w &=? & &
 \end{aligned}$$



$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_w + \vec{F}_g$$

$$(65)(-49) = -F_w + 637$$

$$F_w = \boxed{3800N}$$

Notice that the sign of the force is positive, even though it is upward and we chose down as positive. This is because we already put the negative sign in the equation ( $-F_w$ ) so  $F_w$  is a scalar quantity. The force that the water must exert is 3800 N upward.

3. A person fishing hooks a 2.0 kg fish on a line that can only sustain a maximum of 38 N of force before breaking. At one point while reeling in the bass, it fights back with a force of 40 N (including its own weight). What is the minimum acceleration with which you must play out the line during this time in order to keep the line from breaking?



Using up as positive,

$$m = 2.0kg$$

$$\vec{F}_{line} = 38N$$

$$\vec{F}_{fish} = -40N$$

$$\vec{a} = ?$$

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_{line} + \vec{F}_{fish}$$

$$2.0\vec{a} = 38 - 40$$

$$\vec{a} = \boxed{-1.0m/s^2}$$

The person would have to let the line out at a rate of 1.0 m/s<sup>2</sup>.

4. The maximum force a grocery bag can withstand and not rip is 250 N. If 20.0 kg of groceries are lifted from the floor to the table with an acceleration of 5.0 m/s<sup>2</sup>, will the bag hold?

In order for the bag not to rip, the force that the bag exerts ( $F_b$ ) must be less than or equal to 250N. Looking at our other information, and using up as positive,

$$\vec{a} = 5.0m/s^2$$

$$m = 20.0kg$$

$$g = 9.80m/s^2$$

$$F_b = ?$$

$$F_g = mg$$

$$= (20.0)(9.80)$$

$$= 196N$$



$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_b + \vec{F}_g$$

$$(20.0)(5.00) = F_b - 196$$

$$F_b = \boxed{296N}$$

Since  $F_b > 250N$ , the bag will break.

5. A student stands on a bathroom scale in an elevator at rest on the 64<sup>th</sup> floor of a building. The scale reads 836 N.

- (a) As the elevator moves up, the scale reading increases to 935 N, then decreases back to 836 N. Find the acceleration of the elevator.

At rest, the force of gravity will be equal to the force that the scale reads. We can use this information to find the mass of the student.

$$F_s = 836N$$

$$g = 9.80m/s^2$$

$$m = ?$$

$$F_s = F_g$$

$$F_s = mg$$

$$836 = m(9.80)$$

$$m = 85.3kg$$

When the scale reading increases, the force that the scale exerts is no longer equal to the force of gravity.



Using up as positive

$$\begin{aligned}
 F_s &= 935\text{N} & m\vec{a} &= \sum \vec{F} \\
 m &= 85.3\text{kg} & m\vec{a} &= \vec{F}_s + \vec{F}_g \\
 \vec{a} &=? & m\vec{a} &= F_s - F_g \\
 & & (85.3)\vec{a} &= 935 - 836 \\
 & & \vec{a} &= \boxed{1.16\text{m/s}^2}
 \end{aligned}$$

The elevator is accelerating upward at  $1.16\text{ m/s}^2$ .

- (b) As the elevator approaches the 74<sup>th</sup> floor, the scale reading drops as low as  $782\text{ N}$ . What is the acceleration of the elevator?



Continuing to use up as positive,

$$\begin{aligned}
 F_s &= 782\text{N} & m\vec{a} &= \sum \vec{F} \\
 m &= 85.3\text{kg} & m\vec{a} &= \vec{F}_s + \vec{F}_g \\
 F_g &= 836\text{N} & m\vec{a} &= F_s - F_g \\
 \vec{a} &=? & (85.3)\vec{a} &= 782 - 836 \\
 & & \vec{a} &= \boxed{-0.633\text{m/s}^2}
 \end{aligned}$$

The elevator is accelerating downward at  $0.633\text{ m/s}^2$ .

6. A person weighing  $490\text{ N}$  stands on a scale (calibrated in newtons) in an elevator.

- (a) What does the scale read when the elevator is at rest?

$$\vec{a} = 0$$

$$F_g = 490\text{N}$$

At rest, the scale pushing up and the force of gravity pushing down must be equal:



This can be shown with Newton's Second Law as well (using up as positive):

$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_s + \vec{F}_g \\
 m(0) &= F_s - F_g \\
 F_s &= F_g \\
 &= \boxed{490N}
 \end{aligned}$$

- (b) What is the reading on the scale when the elevator ascends at a constant acceleration of  $2.7 \text{ m/s}^2$ ?

Using up as positive again,

$$\begin{aligned}
 \vec{a} &= 2.7 \text{ m/s}^2 & F_g &= mg \\
 F_g &= 490 \text{ N} & 490 &= m(9.80) \\
 g &= 9.80 \text{ m/s}^2 & m &= 50 \text{ kg} \\
 F_s &=? & &
 \end{aligned}$$



$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_s + \vec{F}_g \\
 (50)(2.7) &= F_s - 490 \\
 F_s &= \boxed{630N}
 \end{aligned}$$

- (c) What is the reading when the elevator ascends at a constant speed of  $7.5 \text{ m/s}$ ?

Since the speed is constant, the acceleration is zero; therefore, the answer is the same as (a) and the scale will read 490 N.

- (d) What is the reading when the elevator slows down to a stop at the top floor, assuming he starts decelerating from his constant speed of  $7.5 \text{ m/s}$  when he is  $3.5 \text{ m}$  away from the top floor?

Using up as positive, we must first find the acceleration:

$$\begin{aligned} \vec{a} &= ? \\ \vec{v}_i &= 7.5 \text{ m/s} \\ \vec{v}_f &= 0 \\ \Delta \vec{d} &= 3.5 \text{ m} \end{aligned} \qquad \begin{aligned} \Delta \vec{d} &= \frac{v_f^2 - v_i^2}{2\vec{a}} \\ 3.5 &= \frac{0 - 7.5^2}{2\vec{a}} \\ \vec{a} &= -8.0 \text{ m/s}^2 \end{aligned}$$



$$\begin{aligned} m\vec{a} &= \sum \vec{F} \\ m\vec{a} &= \vec{F}_s + \vec{F}_g \\ (50.)(-8.0) &= F_s - 490 \\ F_s &= \boxed{90\text{N}} \end{aligned}$$

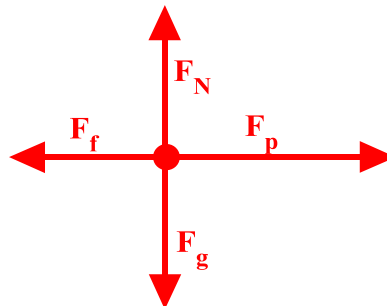
- (e) Suppose the cable snapped and the elevator fell freely. What would the scale read?

Continuing to use up as positive,

$$\begin{aligned} \vec{a} &= -9.80 \text{ m/s}^2 \\ F_g &= 490 \text{ N} \\ m &= 50. \text{ kg} \\ F_s &= ? \end{aligned} \qquad \begin{aligned} m\vec{a} &= \sum \vec{F} \\ m\vec{a} &= \vec{F}_s + \vec{F}_g \\ (50.)(-9.80) &= F_s - 490 \\ F_s &= \boxed{0\text{N}} \end{aligned}$$

As expected, the scale will not read anything – the person will feel weightless. This is apparent weightlessness, since gravity is still acting on the person.

7. A 5.5 kg object is being pushed to the right with a force of 65 N. If the acceleration of the object is 3.0 m/s<sup>2</sup> to the right, what is the coefficient of friction?





$$\vec{a} = 3.0 \text{ m/s}^2$$

$$m = 5.5 \text{ kg}$$

$$F_p = 65 \text{ N}$$

$$g = 9.80 \text{ m/s}^2$$

$$\mu = ?$$

$$F_g = mg$$

$$= (5.5)(9.80)$$

$$= 53.9 \text{ N}$$

Looking at the vertical forces, the normal force must equal the force of gravity since there is no vertical acceleration.

$$F_N = F_g$$

$$= 53.9 \text{ N}$$

Looking at the horizontal forces (and using the right as positive)

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_p + \vec{F}_f$$

$$5.5(3.0) = 65 - F_f$$

$$F_f = 48.5 \text{ N}$$

and

$$F_f = \mu F_N$$

$$48.5 = \mu(53.9)$$

$$\mu = \boxed{0.90}$$

8. What is the acceleration of a falling 65.0 kg skydiver if air resistance exerts a force of 250. N?

$$m = 65.0 \text{ kg}$$

$$g = 9.80 \text{ m/s}^2$$

$$F_a = 250. \text{ N}$$

$$\vec{a} = ?$$

$$F_g = mg$$

$$= (65.0)(9.80)$$

$$= 637 \text{ N}$$



Using up as positive,

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_a + \vec{F}_g$$

$$m\vec{a} = F_a - F_g$$

$$65.0\vec{a} = 250. - 637$$

$$\vec{a} = -5.95 \text{ m/s}^2$$

The acceleration is 5.95 m/s<sup>2</sup> down (the direction is indicated by the negative sign).

9. The cable supporting a 1650 kg elevator has a maximum strength of 22500 N. What maximum upward acceleration can the cable give the elevator without breaking?

$$m = 1650 \text{ kg}$$

$$F_T = 22500 \text{ N}$$

$$g = 9.80 \text{ m/s}^2$$

$$\vec{a} = ?$$

$$\begin{aligned} F_g &= mg \\ &= (1650)(9.80) \\ &= 16170 \text{ N} \end{aligned}$$



Using up as positive,

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_T + \vec{F}_g$$

$$m\vec{a} = F_T - F_g$$

$$1650\vec{a} = 22500 - 16170$$

$$\vec{a} = \boxed{3.84 \text{ m/s}^2}$$

10. You are driving a car at a constant speed of 14.0 m/s along an icy road. All of a sudden, your physics teacher jumps in front of your car! You slam on the brakes. Your wheels lock, the tires begin skidding, and the car slides to a halt in a distance of 25.0 m. What is the coefficient of sliding friction between your tires and the icy roadbed?

$$\vec{v}_i = 14.0 \text{ m/s}$$

$$\vec{v}_f = 0$$

$$\Delta \vec{d} = 25.0 \text{ m}$$

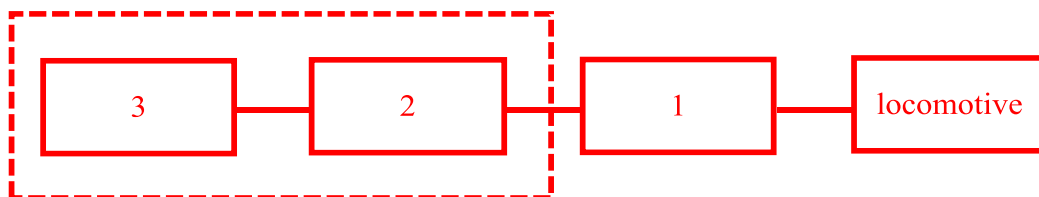
$$\mu = ?$$

$$\begin{aligned} \Delta \vec{d} &= \frac{v_f^2 - v_i^2}{2\vec{a}} \\ 25.0 &= \frac{0 - 14.0^2}{2\vec{a}} \\ \vec{a} &= -3.92 \text{ m/s}^2 \end{aligned}$$

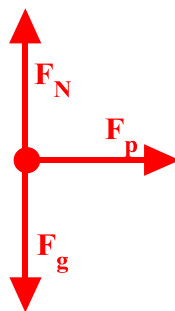
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$$\begin{aligned}
m\vec{a} &= \sum \vec{F} \\
m\vec{a} &= \vec{F}_f \\
m\vec{a} &= -F_f \\
m\vec{a} &= -\mu F_N \\
m\vec{a} &= -\mu mg \text{ (since the normal force must equal the force of gravity)} \\
-3.92 &= -\mu(9.80) \\
\mu &= \boxed{0.40}
\end{aligned}$$

11. A train locomotive pulling three identical 8850 kg cars accelerates at 0.225 m/s<sup>2</sup>. With what force does the first car pull the second?



Since the first car is actually pulling cars 2 and 3, we can treat them as one object. Since there is no obvious friction in this problem, this force is the only horizontal force.



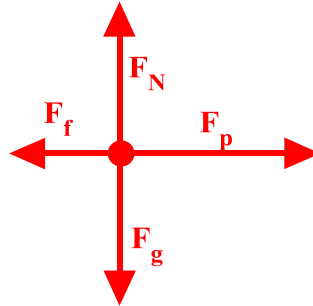
$$\begin{aligned}
m &= 17700 \text{ kg (the mass of cars 2 and 3)} \\
\vec{a} &= 0.225 \text{ m/s}^2 \\
F_p &= ?
\end{aligned}$$

$$\begin{aligned}
m\vec{a} &= \sum \vec{F} \\
m\vec{a} &= \vec{F}_p \\
17700(0.225) &= F_p \\
F_p &= \boxed{3980 \text{ N}}
\end{aligned}$$

12. Suppose that the locomotive in the last problem has a mass of 23500 kg, and that the friction force on each of the three cars is 1100 N. If the

acceleration is the same as in the last problem, what must be the horizontal force that the locomotive exerts against the rails?

This time, we can treat the locomotive and all 3 cars as one object. When the locomotive exerts a horizontal force backward against the rails, the rails exert an equal forward force against the locomotive (Newton's Third Law); this is the pushing force that accelerates the train and what we are trying to find.



$$m = 50050\text{kg (the total mass of the 3 cars and the locomotive)}$$

$$F_f = 3300\text{N}$$

$$\vec{a} = 0.225\text{m/s}^2$$

$$F_p = ?$$

Since the acceleration is horizontal, we can only include horizontal forces to calculate the acceleration.

$$m\vec{a} = \sum \vec{F}$$

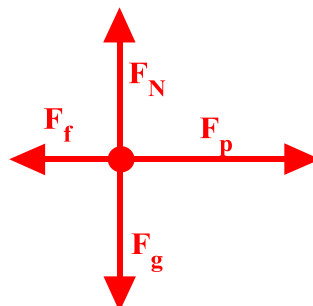
$$m\vec{a} = \vec{F}_p + \vec{F}_f$$

$$(50050)(0.225) = F_p - 3300$$

$$F_p = \boxed{14600\text{N}}$$

Since there is 14600 N of force pushing the locomotive forward, this is also the size of the force that the locomotive must push against the rails with.

13. A horizontal force of 85 N is applied to a box on a table, resulting in an acceleration of  $3.2\text{ m/s}^2$ . If the coefficient of friction between the box and the table is 0.41, find the mass of the box.



$$F_p = 85N$$

$$a = 3.2m/s^2$$

$$\mu = 0.41$$

$$g = 9.80m/s^2$$

$$m = ?$$

**vertical**

$$F_N = F_g$$

$$= mg$$

$$= 9.80m$$

**horizontal**

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_p + \vec{F}_f$$

$$m\vec{a} = F_p - F_f$$

$$m\vec{a} = F_p - \mu F_N$$

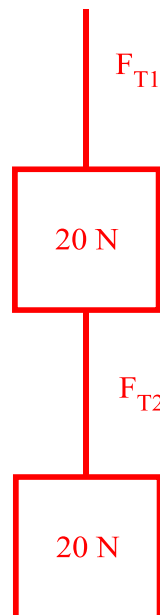
$$m(3.2) = 85 - 0.41(9.80m)$$

$$3.2m = 85 - 4.0m$$

$$7.2m = 85$$

$$m = \boxed{12kg}$$

14. One paint bucket weighing 20.0 N is hanging by a massless rope from another paint bucket also weighing 20.0 N, and the two are being pulled upward with an acceleration of 1.65 m/s<sup>2</sup> by another massless rope attached to the upper bucket. Calculate the tension in each rope.



To find  $F_{T1}$ , we will treat both paint cans as one big object (since the top rope is lifting both cans)

$$F_g = 40.0\text{N}$$

$$g = 9.80\text{m/s}^2$$

$$\vec{a} = 1.65\text{m/s}^2$$

$$F_{T1} = ?$$

$$F_g = mg$$

$$40.0 = m(9.80)$$

$$m = 4.08\text{kg}$$



Using up as positive,

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_{T1} + \vec{F}_g$$

$$m\vec{a} = F_{T1} - F_g$$

$$4.08(1.65) = F_{T1} - 40.0$$

$$F_{T1} = \boxed{46.7\text{N}}$$

To find  $F_{T2}$ , we only need to look at the bottom can (since the top rope is lifting just the bottom can)

$$F_g = 20.0\text{N}$$

$$g = 9.80\text{m/s}^2$$

$$\vec{a} = 1.65\text{m/s}^2$$

$$F_{T2} = ?$$

$$F_g = mg$$

$$20.0 = m(9.80)$$

$$m = 2.04\text{kg}$$



Using up as positive,

$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_{T_2} + \vec{F}_g \\
 m\vec{a} &= F_{T_2} - F_g \\
 2.04(1.65) &= F_{T_2} - 20.0 \\
 F_{T_2} &= \boxed{23.4N}
 \end{aligned}$$

Notice that the top rope is exerting twice as much force as the bottom rope, which makes sense since it is lifting twice the mass.

15. A  $5000 \text{ kg}$  helicopter accelerates upward at  $0.550 \text{ m/s}^2$  while lifting a  $1500 \text{ kg}$  car.

(a) What is the lift force exerted by the air on the propellers?

The lift force exerted on the propellers is actually lifting the helicopter and the car, so we will treat the two of them as one object. Using up as positive,

$$\begin{aligned}
 m &= 6500 \text{ kg} & F_g &= mg \\
 \vec{a} &= 0.550 \text{ m/s}^2 & &= (6500)(9.80) \\
 g &= 9.80 \text{ m/s}^2 & &= 63700 \text{ N} \\
 F_L &=? & &
 \end{aligned}$$



$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_L + \vec{F}_g \\
 m\vec{a} &= F_L - F_g \\
 6500(0.550) &= F_L - 63700 \\
 F_L &= \boxed{67300N}
 \end{aligned}$$

(b) What is the tension in the cable that connects car to helicopter?

This time, the cable is lifting only the car so we will use the car alone as our object.

$$m = 1500\text{kg}$$

$$\vec{a} = 0.550\text{m/s}^2$$

$$g = 9.80\text{m/s}^2$$

$$F_c = ?$$

$$F_g = mg$$

$$= (1500)(9.80)$$

$$= 14700\text{N}$$



$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_c + \vec{F}_g$$

$$m\vec{a} = F_c - F_g$$

$$1500(0.550) = F_c - 14700$$

$$F_c = \boxed{15500\text{N}}$$

16. A motorcyclist is coasting with the engine off at a steady speed of  $12\text{ m/s}$ , but enters a sandy stretch where the coefficient of friction is  $0.80$ . Will the motorcyclist emerge from the sandy stretch without having to start the engine if the sand lasts for  $15\text{ m}$ ? If so, what will be the speed upon emerging?

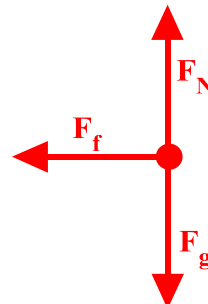
Since we do not know if the motorcyclist makes it or not, we will assume that he does not make it and find out how far he travels before stopping. If this is less than  $15\text{ m}$ , then our assumption was right.

$$\vec{v}_i = 12\text{m/s}$$

$$\vec{v}_f = 0$$

$$\mu = 0.80$$

$$\Delta\vec{d} = ?$$



Looking at the vertical forces, we know that



$$F_N = F_g$$

Since there is no vertical acceleration.

Looking at the horizontal forces (and using forward as positive),

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_f$$

$$m\vec{a} = -F_f$$

$$m\vec{a} = -\mu F_N$$

$$\mu\vec{a} = -\mu\cancel{m}g$$

$$\vec{a} = -(0.80)(9.80)$$

$$= -7.84\text{m/s}^2$$

$$\Delta\vec{d} = \frac{v_f^2 - v_i^2}{2\vec{a}}$$

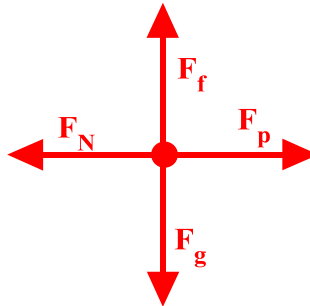
$$= \frac{0 - 12^2}{2(-7.84)}$$

$$= \boxed{9.2\text{m}}$$

Since  $9.2\text{m} < 15\text{m}$ , the motorcyclist did not make it out of the sandy stretch.

17. You are pushing a  $3.2\text{ kg}$  box horizontally with your hand against a vertical wall. The coefficient of friction between the box and the wall is  $0.35$ .

(a) If the box slides down the wall with an acceleration of  $2.3\text{ m/s}^2$ , with how much force were you pushing with your hand?



$$m = 3.2\text{kg}$$

$$g = 9.80\text{m/s}^2$$

$$\mu = 0.35$$

$$\vec{a} = 2.3\text{m/s}^2 \text{ (down)}$$

$$F_p = ?$$

$$F_g = mg$$

$$= (3.2)(9.80)$$

$$= 31.4\text{N}$$

Looking at the vertical forces (and using down as positive),

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_f + \vec{F}_g$$

$$m\vec{a} = -F_f + F_g$$

$$3.2(2.3) = -F_f + 31.4$$

$$F_f = 24\text{N}$$

$$F_f = \mu F_N$$

$$\text{and } 24 = (0.35)F_N$$

$$F_N = 69\text{N}$$

Since  $F_p = F_N$  (from the free body diagram)

$$F_p = F_N$$

$$= \boxed{69N}$$

(b) How hard would you have to push to stop the box from moving?

For no motion, the acceleration is zero so

$$F_f = F_g$$

$$= 31.4N$$

And

$$F_f = \mu F_N$$

$$31.4 = (0.35)F_N$$

$$F_N = 90N$$

so

$$F_p = F_N$$

$$= \boxed{90N}$$

18. A person falls from a tower 5.0 m high. When he strikes the ground below, he bends his knees so that his torso decelerates over an approximate distance of 0.70 m. If the mass of his torso (excluding legs) is 50.0 kg, find the average force exerted on his torso by his legs during the deceleration.

It is necessary to break this problem up into two parts – the falling part and the landing part. We will use down as positive in both parts.

Part 1 – Falling

$$\vec{a} = 9.80m/s^2$$

$$\vec{v}_i = 0$$

$$\Delta\vec{d} = 5.0m$$

$$\vec{v}_f = ?$$

$$\Delta\vec{d} = \frac{v_f^2 - v_i^2}{2\vec{a}}$$

$$5.0 = \frac{v_f^2 - 0}{2(9.80)}$$

$$v_f = 9.9m/s$$

Part 2 – Landing

$$\vec{v}_i = 9.9m/s$$

$$\vec{v}_f = 0$$

$$\Delta\vec{d} = 0.70m$$

$$\vec{a} = ?$$

$$\Delta\vec{d} = \frac{v_f^2 - v_i^2}{2\vec{a}}$$

$$0.70 = \frac{0 - 9.9^2}{2\vec{a}}$$

$$\vec{a} = -70.0m/s^2$$

Knowing the acceleration, we can now look at the forces:



$$\vec{a} = -70.0 \text{ m/s}^2$$

$$m = 50.0 \text{ kg}$$

$$g = 9.80 \text{ m/s}^2$$

$$F_L = ?$$

$$F_g = mg$$

$$= (50.0)(9.80)$$

$$= 490 \text{ N}$$

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_L + \vec{F}_g$$

$$m\vec{a} = -F_L + F_g$$

$$50.0(-70.) = -F_L + 490$$

$$F_L = \boxed{4000 \text{ N}}$$

19. An exceptional standing jump would raise a person  $0.80 \text{ m}$  off the ground. To do this, what force must a  $70.0 \text{ kg}$  person exert against the ground? Assume the person lowers himself  $0.20 \text{ m}$  prior to jumping.

It is necessary to break this problem up into two parts, on the ground and in the air. We will use up as the positive direction.

**On the ground**

$$\Delta \vec{d} = 0.20 \text{ m}$$

$$\vec{v}_i = 0$$

$$m = 70.0 \text{ kg}$$

**In the air**

$$\Delta \vec{d} = 0.80 \text{ m}$$

$$\vec{v}_f = 0 \text{ (at the top of the jump)}$$

$$\vec{a} = -9.80 \text{ m/s}^2$$

$$m = 70.0 \text{ kg}$$

If we can find the speed at which the person leaves the ground (the initial velocity from part 2) we can use this as the final velocity in part 1.

$$\Delta \vec{d} = \frac{v_f^2 - v_i^2}{2\vec{a}}$$

$$0.80 = \frac{0 - v_i^2}{2(-9.80)}$$

$$\vec{v}_i = 3.96 \text{ m/s}$$

We can now find the acceleration while pushing against the ground that the person needs to get this speed:

$$\Delta \vec{d} = \frac{v_f^2 - v_i^2}{2\vec{a}}$$

$$0.20 = \frac{3.96^2 - 0}{2\vec{a}}$$

$$\vec{a} = 39.2 \text{ m/s}^2$$

The forces acting on the person are the force of the ground (the normal force) and the force of gravity:



$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_N + \vec{F}_g$$

$$m\vec{a} = F_N - mg$$

$$(70.0)(39.2) = F_N - (70.0)(9.80)$$

$$F_N = 3400 \text{ N}$$

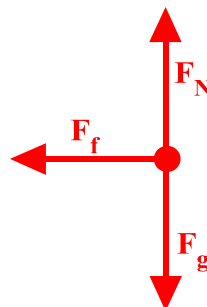
Since the ground is exerting an upward force of 3400 N on the person, the person must be exerting an equal downward force on the ground (Newton's Third Law).

$$F_p = F_N$$

$$= \boxed{3400 \text{ N}}$$

20. A box is given an initial push so that it slides across the floor. How far will it go, given that the coefficient of friction is 0.30 and the push imparts an initial speed of 3.0 m/s?

Since the box was only given an initial push, there is no longer any force pushing the box forward.



$$\vec{v}_i = 3.0 \text{ m/s}$$

$$\vec{v}_f = 0$$

$$\mu = 0.30$$

$$\Delta \vec{d} = ?$$

To find the displacement, we first need the acceleration

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_f$$

$$m\vec{a} = -F_f$$

$$m\vec{a} = -\mu F_N$$

$$\mu\vec{a} = -\mu g$$

$$\vec{a} = -(0.30)(9.80)$$

$$\vec{a} = -2.94 \text{ m/s}^2$$

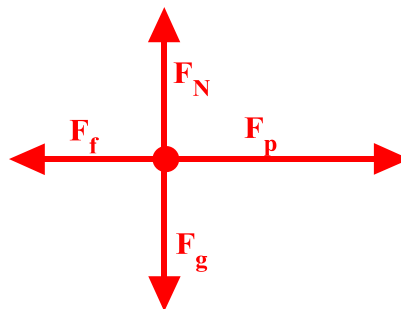
$$\begin{aligned} \Delta \vec{d} &= \frac{v_f^2 - v_i^2}{2\vec{a}} \\ &= \frac{0 - 3.0^2}{2(-2.94)} \\ &= \boxed{1.5 \text{ m}} \end{aligned}$$

and then

21. Two crates, of mass 80. kg and 120. kg, are in contact and rest on a horizontal surface. A 700. N horizontal force is exerted on the 80. kg crate toward the second crate. If the coefficient of kinetic friction is 0.250, calculate

(a) the acceleration of the system

To find the acceleration of the system, we can treat both boxes as one object:



Using right as positive in this problem,

$$m = 200. \text{ kg}$$

$$\mu = 0.250$$

$$g = 9.80 \text{ m/s}^2$$

$$F_p = 700. \text{ N}$$

$$F_g = mg$$

$$= (200.)(9.80)$$

$$= 1960 \text{ N}$$

$$F_f = \mu F_N$$

$$= (0.250)(1960)$$

$$= 490. \text{ N}$$

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_p + \vec{F}_f$$

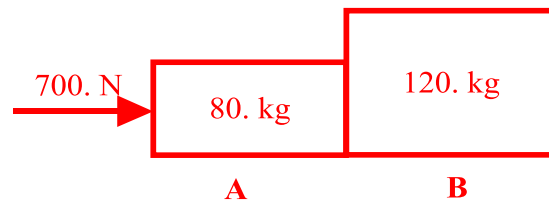
$$m\vec{a} = F_p - F_f$$

$$(200.)\vec{a} = 700. - 490.$$

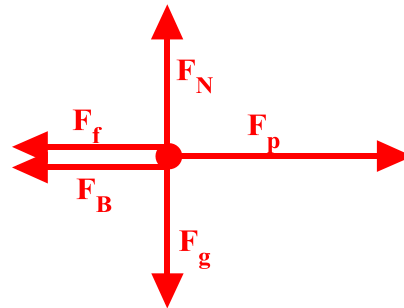
$$\vec{a} = \boxed{1.05 \text{ m/s}^2}$$

(b) the force that each crate exerts on the other

For this part, it is necessary to look at the individual boxes:



Looking at the 80. kg box (box A),



$$m = 80. \text{ kg}$$

$$\vec{a} = 1.05 \text{ m} / \text{ s}^2$$

$$\mu = 0.25$$

$$F_p = 700. \text{ N}$$

$$g = 9.80 \text{ m} / \text{ s}^2$$

$$F_g = mg$$

$$= (80.) (9.80)$$

$$= 784 \text{ N}$$

$$F_f = \mu F_N$$

$$= (0.250) (784)$$

$$= 196 \text{ N}$$

$$m\vec{a} = \sum \vec{F}$$

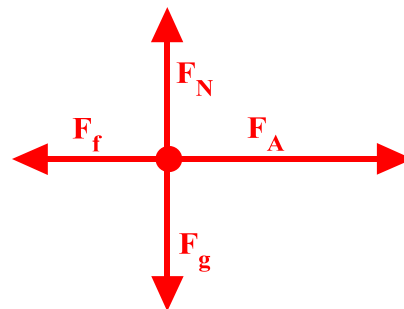
$$m\vec{a} = \vec{F}_p + \vec{F}_f + \vec{F}_B$$

$$m\vec{a} = F_p - F_f - F_B$$

$$(80.) (1.05) = 700. - 196 - F_B$$

$$F_B = \boxed{420 \text{ N}}$$

Looking at the 120. Kg box (box B),



Notice that the 700. N force is not included since it is not acting directly on the 120. kg box.

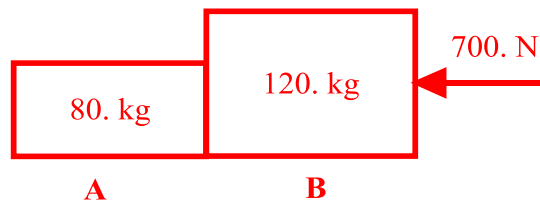
$$\begin{array}{lll}
 m = 120. \text{ kg} & F_g = mg & F_f = \mu F_N \\
 \mu = 0.25 & = (120.)(9.80) & = (0.250)(1176) \\
 g = 9.80 \text{ m/s}^2 & = 1176 \text{ N} & = 294 \text{ N}
 \end{array}$$

$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_A + \vec{F}_f \\
 m\vec{a} &= F_A - F_f \\
 (120.)(1.05) &= F_A - 294 \\
 F_A &= \boxed{420 \text{ N}}
 \end{aligned}$$

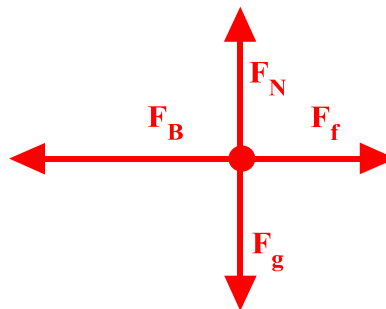
Notice that  $F_A$  and  $F_B$  are the same size! Of course this should be true according to Newton's Second Law. Because of this, it was only necessary to calculate one or the other, since we know that they must be equal.

- (c) Repeat part (b) assuming the 700 N force is exerted on the 120 kg crate (in the opposite direction)

For this part, it is necessary to look at the individual boxes:



Looking at the 80. kg box (box A),



$$m = 80. \text{ kg}$$

$$F_f = 196 \text{ N}$$

$$\vec{a} = -1.05 \text{ m/s}^2 \text{ (since the boxes will now be moving in the opposite direction)}$$

$$F_B = ?$$

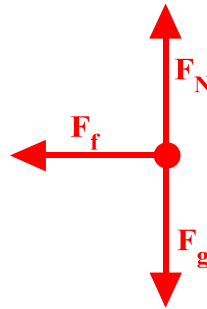
$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_B + \vec{F}_f \\
 m\vec{a} &= -F_B + F_f \\
 (80.)(-1.05) &= -F_B + 196 \\
 F_B &= \boxed{280N}
 \end{aligned}$$

And because of Newton's Third Law.

$$\begin{aligned}
 F_A &= F_B \\
 F_A &= \boxed{280N}
 \end{aligned}$$

22. A flatbed truck is carrying a 2800 kg crate of heavy machinery. If the coefficient of static friction between the crate and the bed of the truck is 0.55, what is the maximum rate at which the driver can slow down when coming to a stop in order to avoid crushing the cab with the crate?

In order for the crate to not crush the cab, it will have to have the same acceleration as the truck. The only horizontal force acting on the crate to slow it down is the force of static friction; therefore, it is necessary to find the maximum acceleration that this force of static friction can provide.



$$\begin{aligned}
 m &= 2800\text{kg} \\
 \mu &= 0.55 \\
 g &= 9.80\text{m/s}^2 \\
 \vec{a} &= ?
 \end{aligned}$$

$$\begin{aligned}
 F_g &= mg \\
 &= (2800)(9.80) \\
 &= 27400\text{N}
 \end{aligned}$$

$$\begin{aligned}
 F_f &= \mu F_N \\
 &= (0.55)(27400) \\
 &= 15000\text{N}
 \end{aligned}$$

$$\begin{aligned}
 m\vec{a} &= \sum \vec{F} \\
 m\vec{a} &= \vec{F}_f \\
 m\vec{a} &= -F_f \\
 2800\vec{a} &= -15000 \\
 \vec{a} &= \boxed{-5.4\text{m/s}^2}
 \end{aligned}$$

Alternate Solution:



$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_f$$

$$m\vec{a} = -F_f$$

$$m\vec{a} = -\mu F_N$$

$$m\vec{a} = -\mu mg$$

$$\vec{a} = -\mu g$$

$$\vec{a} = -(0.55)(9.80)$$

$$\vec{a} = \boxed{-5.4 \text{ m/s}^2}$$

23. A 40.0 kg child wants to escape from a third story window to avoid punishment. Unfortunately, a makeshift rope made of sheets can only support a mass of 30.0 kg.

(a) How can the child use this “rope” to escape? Give a quantitative answer.

**Force that rope can exert :**

$$\begin{aligned} F_r &= mg \\ &= (30.0)(9.80) \\ &= 294 \text{ N} \end{aligned}$$

**Weight of child:**

$$\begin{aligned} F_g &= mg \\ &= (40.0)(9.80) \\ &= 392 \text{ N} \end{aligned}$$

Since the rope cannot support the child’s weight, it will be necessary for the child to accelerate downward so that the rope does not have to exert as much upward force.



A quantitative answer requires a value for this acceleration. Using up as positive:

$$m\vec{a} = \sum \vec{F}$$

$$m\vec{a} = \vec{F}_r + \vec{F}_g$$

$$m\vec{a} = F_r - F_g$$

$$40.0\vec{a} = 294 - 392$$

$$\vec{a} = \boxed{-2.45 \text{ m/s}^2}$$

Basically, the child is using the “rope” to slow himself down so that he only accelerates downward at  $2.45 \text{ m/s}^2$ , rather than  $9.80 \text{ m/s}^2$  if he jumped from the window.

(b) Give one example of a pair of forces that demonstrates Newton’s Third Law in this problem.

Some acceptable answers include:

- The force of the Earth pulling down on the child and the force of the child pulling up on the Earth
- The force of the child pulling down on the bedsheets, the force of the bedsheets pulling up on the child
- The force of the bedsheets pulling down on the bed (or whatever they are tied to) and the force of the bed pulling up on the bedsheets