Chapter 4: Applications of Forces

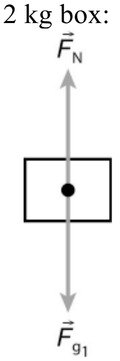
Mini Investigation: Friction from Shoes, page 161

A. Answers may vary. Sample answer:
A large or heavier shoe likely experiences a greater frictional force than a smaller size or lighter shoe. Dividing the maximum force of friction by the force of gravity of the shoe eliminates the effect of mass on the frictional force, thus making the comparison of the results fairer.

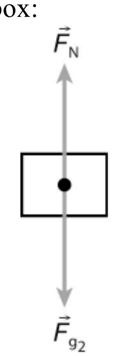
Section 4.1: Gravitational Force Near Earth

Tutorial 1 Practice, page 166

1. (a) FBD for the 12 kg box:



FBD for the 38 kg box:



(b) Choose up as positive. So down is negative.
Determine the force of gravity of the box.

$$F_{g1} = m_1 g$$
$$= (12\text{ kg})(-9.8\text{ m/s}^2)$$
$$F_{g1} = -120\text{ N}$$

Since the box is at rest, the net force on the box is zero.

$$F_N + F_{g1} = 0$$
$$F_N + (-120\text{ N}) = 0$$
$$F_N = +120\text{ N}$$

The normal force acting on the box is 120 N [up].

(c) Choose up as positive. So down is negative.
Determine the force of gravity of the box.

$$F_{g2} = (m_1 + m_2)g$$
$$= (12\text{ kg} + 38\text{ kg})(-9.8\text{ m/s}^2)$$
$$F_{g2} = -490\text{ N}$$

Since the box is at rest, the net force on the box is zero.

$$F_N + F_{g2} = 0$$
$$F_N + (-490\text{ N}) = 0$$
$$F_N = +490\text{ N}$$

The normal force acting on the box is 490 N [up].

2. (a) When the child is moving up at a constant velocity, the child is not accelerating. So the net force on the child is zero.
Choose up as positive. So down is negative.

$$F_N + F_g = 0$$
$$F_N + (36\text{ kg})(-9.8\text{ m/s}^2) = 0$$
$$F_N = +350\text{ N}$$

The normal force acting on the child is 350 N [up].

(b) When the child is moving down at a constant velocity, the child is not accelerating. So the net force on the child is zero.
Choose up as positive. So down is negative.

$$F_N + F_g = 0$$
$$F_N + (36\text{ kg})(-9.8\text{ m/s}^2) = 0$$
$$F_N = +350\text{ N}$$

The normal force acting on the child is 350 N [up].

(c) When the child is accelerating, the net force on the child is given by the equation $F_{net} = ma$.
Choose up as positive. So down is negative.

$$F_N + F_g = F_{net}$$
$$F_N + mg = ma$$
$$F_N = m(a - g)$$
$$= (36\text{ kg})[-1.8\text{ m/s}^2 - (-9.8\text{ m/s}^2)]$$
$$F_N = +290\text{ N}$$

The normal force acting on the child is 290 N [up].

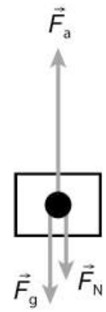
3. When the person is accelerating upward, the net force on the person is given by $F_{net} = ma$.

Choose up as positive. So down is negative.

$$F_N + F_g = F_{net}$$
$$F_N + mg = ma$$
$$a = \frac{F_N + mg}{m}$$
$$= \frac{+840\text{ N} + (72\text{ kg})(-9.8\text{ m/s}^2)}{72\text{ kg}}$$
$$a = +1.9\text{ m/s}^2$$

The acceleration of the person is 1.9 m/s^2 [up].

4. Draw a FBD of the chandelier.



The chandelier is at rest. So the net force on the chandelier is zero.

Choose up as positive. So down is negative.

$$\vec{F}_N + \vec{F}_g + \vec{F}_a = 0$$
$$F_N + (3.2\text{ kg})(-9.8\text{ m/s}^2) + 53\text{ N} = 0$$
$$F_N = -22\text{ N}$$

The normal force acting on the chandelier is 22 N [down].

Section 4.1 Questions, page 167

1. (a) According to Newton's second law, the net force acting on an object is given by the equation $\vec{F}_{net} = m\vec{a}$. In the absence of air resistance, the only force acting on a falling object is the force of gravity given by the equation $F_g = mg$.

For all objects,

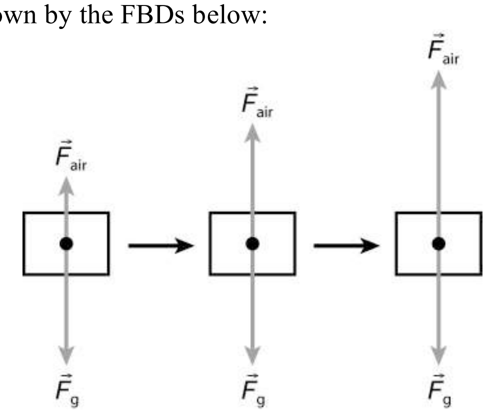
$$ma = mg$$
$$a = g$$

Therefore, in the absence of air resistance, all objects fall with the same acceleration *g*, which equals 9.8 m/s^2 [down].

2. Air resistance increases with the cross-sectional area and the speed of an object. A person with an open parachute has a greater cross-sectional area than the person alone, so the net upward force exerted by the air on the person with an open parachute is greater than that on the person alone. As a result, the downward acceleration of the person with an open parachute is slower and so will be the terminal speed.

3. Since air resistance, friction caused by air, increases with the cross-sectional area, an object with larger cross-sectional area experiences more air resistance than an object with smaller cross-sectional area and will fall more slowly in air. The gravitational field strength pulling an object downward, given by *mg*, increases with the mass of an object so a heavier object falls faster than a lighter object. So light objects with large cross-sectional area fall more slowly in air than heavy objects with small cross-sectional area.

4. As soon as the box leaves the plane, the box accelerates downward due to gravity. The initial acceleration is 9.8 /ms^2 and its speed increases from 0 m/s. As the speed increases, the upward force of air resistance increases. The box with the parachute has a large cross-sectional area, so the air resistance could increase to the point when its magnitude is greater than the force of gravity, as shown by the FBDs below:



When the upward force of air resistance is greater than the downward force of gravity, the net force on the box is directed upward while the box is still falling downward. The acceleration changes direction and the speed of the box decreases. When the box breaks free from the parachute, the air resistance on the box is so small that the only force acting on the box is the force of gravity. The box will be in free fall with an acceleration of 9.8 /ms^2 downward and its speed will increase.

5. (a) The mass of an object does not change with location or gravitational field strength. So the mass of the astronaut on the station is 74 kg.
(b) Weight of the astronaut on Earth's surface:

$$F_g = mg$$
$$= (74\ \cancel{\text{kg}})\left(9.8\,\frac{\text{N}}{\cancel{\text{kg}}}\right)$$
$$F_g = 725.2\ \text{N}$$

Weight of the astronaut on the station:

$$F_{gs} = mg_s$$
$$= (74\ \cancel{\text{kg}})\left(8.6\,\frac{\text{N}}{\cancel{\text{kg}}}\right)$$
$$F_{gs} = 636.4\ \text{N}\ \text{(two extra digits carried)}$$

Find the difference:
725.2 N – 636.4 N = 89 N

The difference between the astronaut's weight on Earth's surface and his weight on the station is 89 N.
(c) The weight of an object is dependent on its location and the magnitude of the gravitational field strength at that location, whereas the mass of an object is the quantity of matter in the object and is independent on its location or the magnitude of the gravitational field strength at that location. So the weight of the astronaut changes but not his mass.
(d) When the station accelerates upward, the astronaut experiences a pull downward on the station due to the force of gravity and feels heavier. When the station accelerates downward, the astronaut feels lighter. As the station orbits Earth, it accelerates downward to a point where the astronaut floats in the station (both the astronaut and the station are under free fall); the astronaut will appear weightless.

6. Table 1

Latitude (°)	Weight of object (N)	$\vec{g}$ (N/kg [down])	Distance from Earth's centre (km)
0 (equator)	**195.61**	9.7805	6378
30	**195.87**	9.7934	6373
60	**196.38**	9.8192	6362
90 (North Pole)	**196.64**	9.8322	6357

(a) 196.64 N – 195.61 N = 1.03 N
The difference in weight of the object from the equator to North Pole is 1.03 N.
(b) The weight changes at different latitudes because it depends on the location and the magnitude of Earth's gravitational field strength at that latitude. The gravitational field strength is greater at the North Pole, which is closer to Earth's centre than that at the equator, which is farther away from Earth's centre.
(c) The gravitational field strength increases with latitude because the greater the latitude (at the North Pole), the closer is the location from Earth's centre. As a result, the attraction by Earth's gravitational field increases.
7. (a) The mass of the cargo box will remain unchanged because the mass of an object is unaffected by its location or the magnitude of the gravitational field strength at that location.
(b) Determine the force of gravity acting on the box. Choose up as positive. So down is negative.

$$F_g = mg$$
$$= (32.00\ \text{kg})(-9.8\ \text{N/kg})$$
$$F_g = -310\ \text{N}$$

The weight of the box on Earth's surface is 310 N.
(c) Use the equation $\vec{F}_g = m\vec{g}$ to determine the gravitational field strength, $\vec{g}_m$, on the surface of the Moon. Choose up as positive. So down is negative.

$$F_m = mg_m$$
$$g_m = \frac{F_m}{m}$$
$$= \frac{-52.06\ \text{N}}{32.00\ \text{kg}}$$
$$g_m = -1.627\ \text{N/kg}$$

The gravitational field strength on the surface of the Moon is 1.627 N/kg [down].

8. Table 2

Quantity	Definition	Symbol	SI unit	Method of measuring	Variation with location
mass	the quantity of matter in an object	m	kg	measure using a balance with standard masses	does not change due to location
weight	a measure of the force of gravity on an object	$\vec{F}_g$	N	measure the force of gravity on object using a spring scale or force sensor and divide by the mass	changes with the gravity of the location

9. Table 3

Planet	Weight (N)	$\vec{g}$ (N/kg)
Mercury	188	**3.3**
Venus	462	**8.1**
Jupiter	**150**	26

10. When an object sits on top of a scale, the reading of the scale is equal to the normal force.

(a) When the object is at rest, $F_{net} = 0$. Add all forces acting on the object. Choose up as positive. So down is negative.

$$F_N + F_g = 0$$

$$F_N + (24\ \cancel{kg})\left(-9.8\ \frac{N}{\cancel{kg}}\right) = 0$$

$$F_N = +240\ N$$

The reading on the scale is 240 N.

(b) When the object is at rest, $F_{net} = 0$. Add all forces acting on the object. Choose up as positive. So down is negative.

$$F_N + F_g + F_a = 0$$

$$F_N + (24\ \cancel{kg})\left(-9.8\ \frac{N}{\cancel{kg}}\right) + (-52\ N) = 0$$

$$F_N = +290\ N$$

The reading on the scale is 290 N.

(c) When the object is at rest, $F_{net} = 0$. Add all forces acting on the object. Choose up as positive. So down is negative.

$$F_N + F_g + F_a = 0$$

$$F_N + (24\ \cancel{kg})\left(-9.8\ \frac{N}{\cancel{kg}}\right) + (+74\ N) = 0$$

$$F_N = +160\ N$$

The reading on the scale is 160 N.

Section 4.2: Friction

Tutorial 1 Practice, page 171

1. (a) Given: m = 22 kg; F_a = 62 N

Required: μ_S

Analysis: Before the box starts to move, F_{net} = 0. To keep the box at rest, $F_{S_{max}} = 62\text{ N}$ acting in the opposite direction. Use the equation $\mu_S = \frac{F_{S_{max}}}{F_N}$ to calculate the coefficient of static friction. Also $F_N = F_g$.

Solution:

$$\mu_S = \frac{F_{S_{max}}}{F_N}$$
$$= \frac{F_{S_{max}}}{mg}$$
$$= \frac{62\text{ N}}{(22\text{ kg})(9.8\text{ m/s}^2)}$$
$$\mu_S = 0.29$$

Statement: The coefficient of static friction is 0.29.

(b) Given: m = 22 kg; F_a = 58 N

Required: μ_K

Analysis: Since the box is moving at a constant velocity, F_{net} = 0. So the kinetic friction on the box is 58 N. Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the coefficient of kinetic friction.

Solution:

$$\mu_K = \frac{F_K}{F_N}$$
$$= \frac{F_K}{mg}$$
$$= \frac{58\text{ N}}{(22\text{ kg})(9.8\text{ m/s}^2)}$$
$$\mu_K = 0.27$$

Statement: The coefficient of kinetic friction is 0.27.

2. Given: m = 75 kg; μ_K = 0.01

Required: F_K

Analysis: Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the magnitude of the force of kinetic friction.

Solution:

$$\mu_K = \frac{F_K}{F_N}$$
$$F_K = \mu_K F_N$$
$$= \mu_K (mg)$$
$$= (0.01)(75\text{ kg})(9.8\text{ m/s}^2)$$
$$F_K = 7.4\text{ N}$$

Statement: The magnitude of the force of kinetic friction acting on the hockey player is 7.4 N.

3. (a) Given: m = 1300 kg; μ_K = 0.5 to 0.80

Required: F_K

Analysis: Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the magnitude of the force of kinetic friction.

Solution: When μ_K = 0.5,

$$\mu_K = \frac{F_K}{F_N}$$
$$F_K = \mu_K F_N$$
$$= \mu_K (mg)$$
$$= (0.5)(1300\text{ kg})(9.8\text{ m/s}^2)$$
$$F_K = 6400\text{ N}$$

When μ_K = 0.80,

$$\mu_K = \frac{F_K}{F_N}$$
$$F_K = \mu_K F_N$$
$$= \mu_K (mg)$$
$$= (0.80)(1300\text{ kg})(9.8\text{ m/s}^2)$$
$$= 10\ 192\text{ N}$$
$$F_K = 1.0 \times 10^4\text{ N}$$

Statement: The magnitude of the force of kinetic friction acting on the car on dry road is 6400 N to 1.0×10^4 N.

(b) Given: m = 1300 kg; μ_K = 0.25 to 0.75

Required: F_K

Analysis: Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the magnitude of the force of kinetic friction.

Solution: When μ_K = 0.25,

$$\mu_K = \frac{F_K}{F_N}$$
$$F_K = \mu_K F_N$$
$$= \mu_K (mg)$$
$$= (0.25)(1300\text{ kg})(9.8\text{ m/s}^2)$$
$$F_K = 3200\text{ N}$$

When $\mu_K = 0.75$,

$$\mu_K = \frac{F_K}{F_N}$$

$$\begin{aligned} F_K &= \mu_K F_N \\ &= \mu_K (mg) \\ &= (0.75)(1300 \text{ kg})(9.8 \text{ m/s}^2) \\ F_K &= 9600 \text{ N} \end{aligned}$$

Statement: The magnitude of the force of kinetic friction acting on the car on wet road is 3200 N to 9600 N.

(c) Given: m = 1300 kg; $\mu_K = 0.005$

Required: F_K

Analysis: Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the magnitude of the force of kinetic friction.

Solution: When $\mu_K = 0.005$,

$$\mu_K = \frac{F_K}{F_N}$$

$$\begin{aligned} F_K &= \mu_K F_N \\ &= \mu_K (mg) \\ &= (0.005)(1300 \text{ kg})(9.8 \text{ m/s}^2) \\ F_K &= 64 \text{ N} \end{aligned}$$

Statement: The magnitude of the force of kinetic friction acting on the car on icy road is 64 N.

Section 4.2 Questions, page 172

1. Answers may vary. Sample answers:

(a) Friction makes the action more difficult when turning a door knob. Friction is helpful because it allows your hand to apply a force on the door knob. Static friction prevents the knob from starting to turn and kinetic friction acts opposite to the motion of turning.

(b) Friction is not helpful in pushing a heavy box across a rough surface as static friction prevents the box from starting to move and kinetic friction acts opposite to the motion of moving.

(c) Friction is not helpful in gliding across smooth ice as kinetic friction acts opposite to the motion of gliding. For demonstrating uniform motion, friction is often made zero.

(d) Friction is helpful and necessary in tying a knot. Static friction on the tied knob prevents the rope or string from slipping out of the knot.

2. Answers may vary. Sample answer:
When you pull the lever on the handle bars, the brake pads of the bicycle wheel are squeezed. A normal force is applied to the rim of the bicycle wheel. The brake pad near the rim will in turn provide a force of friction to the rim, slowing down the bicycle.

3. (a) To start the block moving, the applied force equals the force of static friction. So the static friction on the block is 5.5 N. Use the equation $\mu_S = \frac{F_{S_{max}}}{F_N}$ to calculate the coefficient of static friction.

$$\begin{aligned} \mu_S &= \frac{F_{S_{max}}}{F_N} \\ &= \frac{F_{S_{max}}}{mg} \\ &= \frac{5.5 \text{ N}}{(1.4 \text{ kg})(9.8 \text{ m/s}^2)} \\ \mu_S &= 0.40 \end{aligned}$$

The coefficient of static friction is 0.40.

To keep the block moving at a constant velocity, the applied force equals the kinetic friction. So the kinetic friction on the block is 4.1 N. Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the coefficient of kinetic friction.

$$\begin{aligned} \mu_K &= \frac{F_K}{F_N} \\ &= \frac{F_K}{mg} \\ &= \frac{4.1 \text{ N}}{(1.4 \text{ kg})(9.8 \text{ m/s}^2)} \\ \mu_K &= 0.30 \end{aligned}$$

The coefficient of kinetic friction is 0.30.

(b) The coefficients of friction depend only on the types of materials in contact. The changes in (i) and (iii) will not affect the coefficients of friction and there is no change in the materials involved. The change in (ii) involves changing the type of material in contact so the coefficients of friction will be affected.

(c) (i) Putting an object on the block increases the normal force on the block. Since $F_S = \mu_S F_N = \mu_S mg$ and $F_K = \mu_K F_N = \mu_K mg$, both the static friction and kinetic friction will increase.

(ii) Applying an upward force decreases the normal force on the block. So both the static friction and kinetic friction will decrease.

(iii) Putting slippery grease on the surface will decrease the coefficients of static and kinetic friction. As a result, both the static friction and kinetic friction will decrease.

4. (a) Answers may vary. Sample answer:
The coefficient of kinetic friction for rubber on dry asphalt roads is slightly lower than that on dry concrete roads (0.5 compared to 0.6). However, the coefficient of kinetic friction for rubber on wet asphalt roads could be much lower than that for wet concrete roads (0.25 compared to 0.45). It seems that it is safer to drive on concrete roads, during rainy days in particular.

(b) The coefficient of kinetic friction on wet roads is generally lower than that on dry roads. This means that the force of friction is generally less on wet roads. So drivers should reduce speeds on wet roads to prevent the car from skidding.

(c) In winter, especially when there is freezing rain, the coefficient of kinetic friction of the road surface could be as low as 0.005. With little friction on the roads, cars will skid. Salting roads increases the coefficient of friction on the road surfaces, making driving safer.

5. (a) Given: $m = 110$ kg; $F_a = 380$ N

Required: μ_K

Analysis: Since the trunk is moving at a constant velocity, $F_{net} = 0$. So the kinetic friction on the trunk is 380 N. Use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate the coefficient of kinetic friction.

Solution:

$$\begin{aligned}\mu_K &= \frac{F_K}{F_N}\\ &= \frac{F_K}{mg}\\ &= \frac{380\text{ N}}{(110\text{ kg})(9.8\text{ m/s}^2)}\\ &= 0.353\\ \mu_K &= 0.35\end{aligned}$$

Statement: The coefficient of kinetic friction is 0.35.

(b) Calculate the normal force on the trunk. Choose up as positive. So down is negative.

$$\begin{aligned}F_N + F_g + F_a &= 0\\ F_N + (110\text{ kg})(-9.8\text{ m/s}^2) + 150\text{ N} &= 0\\ F_N &= +928\text{ N}\end{aligned}$$

Use the equation $F_K = \mu_K F_N$ to calculate the force of kinetic friction on the trunk.

$$\begin{aligned}F_K &= \mu_K F_N\\ &= (0.353)(928\text{ N})\\ F_K &= 330\text{ N}\end{aligned}$$

The force required to pull the trunk is 330 N. With the help of the friend, the force required to pull the trunk at a constant velocity is less.

(c) The total mass on the trunk is:
110 kg + 55 kg = 165 kg

Use the equation $F_K = \mu_K F_N = \mu_K mg$ to calculate the force of kinetic friction on the trunk.

$$\begin{aligned}F_K &= \mu_K F_N\\ &= \mu_K mg\\ &= (0.353)(165\text{ kg})(9.8\text{ m/s}^2)\\ F_K &= 570\text{ N}\end{aligned}$$

The force required to pull the trunk at a constant velocity is 570 N.

6. First use the equation $F_S = \mu_S F_N = \mu_S mg$ to calculate the maximum magnitude of static friction acting on the desk.

$$\begin{aligned}F_{S_{max}} &= \mu_S F_N\\ &= \mu_S mg\\ &= (0.25)(26\text{ kg})(9.8\text{ m/s}^2)\\ F_{S_{max}} &= 64\text{ N}\end{aligned}$$

Calculate the applied force. Choose east as positive. So west is negative.

$$\begin{aligned}F_a &= +52\text{ N} + (-110\text{ N})\\ &= -58\text{ N}\\ \vec{F}_a &= 58\text{ N [W]}\end{aligned}$$

The applied force is 58 N [W].

Since the applied force of 58 N is less than the static friction of 64 N, the desk will not move.

7. (a) Given: m = 12 000 kg; μ_S = 0.50

Required: $F_{S_{max}}$

Analysis: To start the bin moving, the minimum force exerted by the truck equals the force of static friction. Use the equation $F_S = \mu_S F_N = \mu_S mg$ to calculate the maximum magnitude of the force of static friction.

Solution:

$$\begin{aligned} F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.50)(12\ 000\ \text{kg})(9.8\ \text{m/s}^2) \\ F_{S_{max}} &= 59\ 000\ \text{N} \end{aligned}$$

Statement: The force exerted by the truck to start the bin moving is 59 000 N.

(b) Given: m = 12 000 kg; μ_K = 0.40

Required: F_K

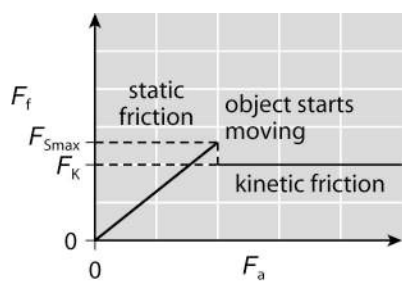
Analysis: To keep the bin moving at a constant velocity, the minimum force exerted by the truck equals the force of kinetic friction. Use the equation $F_K = \mu_K F_N = \mu_K mg$ to calculate the magnitude of the force of kinetic friction.

Solution:

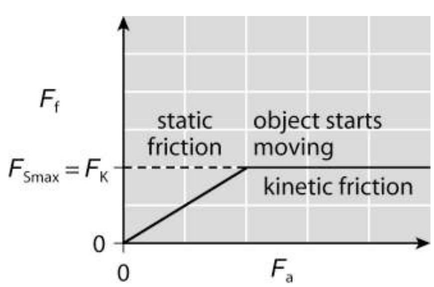
$$\begin{aligned} F_K &= \mu_K F_N \\ &= \mu_K (mg) \\ &= (0.40)(12\ 000\ \text{kg})(9.8\ \text{m/s}^2) \\ F_K &= 47\ 000\ \text{N} \end{aligned}$$

Statement: The force exerted by the truck to keep the bin moving at a constant velocity is 47 000 N.

8. (a)



(b)



9. Answers may vary. Sample answer:
When the wedge is in position, there is friction between the bottom of the wedge and the floor. The force exerted by the door is counteracted by the force of static friction between the bottom of the wedge and the floor.

10. Answers may vary. Sample answers:

(a) First measure the mass of an object using a balance for calculating the force of gravity on the object. Then use a force sensor to pull the stationary object horizontally along a surface. As you increase the applied force of pulling, the reading on the force sensor when the object just starts to move gives the magnitude of the static friction. The coefficient of static friction of the surface is then calculated as the ratio of the magnitude of the force of static friction to the magnitude of the normal force acting on an object. In this case, the magnitude of the normal force equals the force of gravity.

(b) First measure the mass of an object using a balance for calculating the force of gravity on the object. Then use a force sensor to pull the stationary object horizontally along a surface slowly until the object starts to move. Once the object starts to move, decrease the applied force until the object moves at a constant velocity. The reading on the force sensor gives the magnitude of the kinetic friction. The coefficient of kinetic friction of the surface is then calculated as the ratio of the magnitude of the force of kinetic friction to the magnitude of the normal force acting on the object.

11. Answers may vary. Sample answer:
When a runner pushes back on his feet, according to Newton's third law, there is a reaction force, friction in this case, that pushes the runner forwards. Therefore, the manufacturer of a running shoe has to be sure that a running shoe is designed to have a high coefficient of friction that can help the runner accelerate quickly in a race. Dress shoes are not usually used for more than walking, so they do not need a high coefficient of friction.

Section 4.3: Solving Friction Problems

Tutorial 1 Practice, page 174

1. (a) Given: m_T = 52 kg + 34 kg = 86 kg; μ_S = 0.35

Required: $F_{S_{max}}$

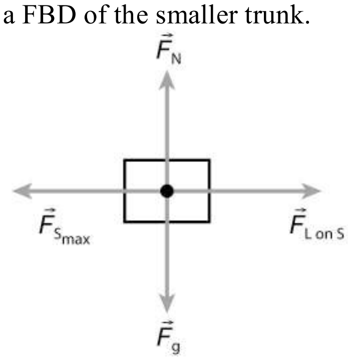
Analysis: $\mu_S = \dfrac{F_{S_{max}}}{F_N}$

Solution:

$$\begin{aligned} F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.35)(86\text{ kg})(9.8\text{ m/s}^2) \\ F_{S_{max}} &= 290\text{ N} \end{aligned}$$

Statement: The magnitude of the maximum force the person can exert without moving either trunk is 290 N.

(b) Draw a FBD of the smaller trunk.



Given: m = 34 kg; μ_S = 0.35

Required: $\vec{F}_{\text{L on S}}$

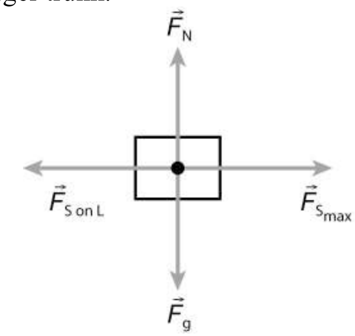
Analysis: Since the smaller trunk does not move, the magnitude of the force that the larger trunk exerts on the smaller trunk equals the magnitude of the static friction acting on the smaller trunk. Use the equation $\mu_S = \dfrac{F_{S_{max}}}{F_N}$ to calculate $F_{S_{max}}$. Choose right as positive. So left is negative.

Solution:

$$\begin{aligned} F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.35)(34\text{ kg})(9.8\text{ m/s}^2) \\ &= +120\text{ N} \\ \vec{F}_{S_{max}} &= 120\text{ N [right]} \end{aligned}$$

Statement: The force that the larger trunk exerts on the smaller trunk is 120 N [right].

(c) Since we can combine the two trunks and treat them as one single object, when the person pushed in the opposite direction on the smaller trunk, the answer to part (a) remains the same. However, the answer to part (b) would change. Look at this FBD of the larger trunk.



When the direction of the pushing force is in the opposite direction, the force exerted by the larger trunk on the smaller trunk will still be to the right. According to the FBD of the larger trunk above, the force that the smaller trunk exerts on the larger trunk is:

$$\begin{aligned} F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.35)(52\text{ kg})(9.8\text{ m/s}^2) \\ &= +180\text{ N} \\ F_{S_{max}} &= 180\text{ N [right]} \end{aligned}$$

So, the force that the larger trunk exerts on the smaller trunk is 180 N [right].

2. Given: m_1 = 4.0 kg; m_2 = 1.8 kg

Required: μ_S

Analysis: The tension is the same throughout the string. First calculate the tension using the equation $F_T = m_2 g$ for the hanging object. As the wooden block is stationary, the tension and the static friction will cancel. So F_T equals $F_{S_{max}}$. Then use the equation $\mu_S = \dfrac{F_{S_{max}}}{F_N}$ to calculate μ_S.

Solution:

$$\begin{aligned} F_T &= m_2 g \\ &= (1.8\text{ kg})(9.8\text{ m/s}^2) \\ F_T &= 17.64\text{ N (two extra digits carried)} \end{aligned}$$

$$\begin{aligned} \mu_S &= \frac{F_{S_{max}}}{F_N} \\ &= \frac{F_T}{m_1 g} \\ &= \frac{17.64\text{ N}}{(4.0\text{ kg})(9.8\text{ m/s}^2)} \\ \mu_S &= 0.45 \end{aligned}$$

Statement: The coefficient of static friction between the wooden block and the table is 0.45.

Tutorial 2 Practice, page 175

1. (a) Given: m = 59 kg; μ_S = 0.52

Required: a

Analysis: First calculate the maximum force of static friction using $F_{S_{max}} = \mu_S F_N$. When the person starts to run, $F_{net} = F_{S_{max}}$. Then use $F_{net} = ma$ to calculate the acceleration.

Solution:

$$\begin{aligned} F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.52)(59\text{ kg})(9.8\text{ m/s}^2) \\ F_{S_{max}} &= 300\text{ N} \end{aligned}$$

Calculate the magnitude of the acceleration.

$$\begin{aligned} F_{net} &= F_{S_{max}} \\ ma &= 300\text{ N} \\ (59\text{ kg})a &= 300\text{ N} \\ a &= 5.1\text{ m/s}^2 \end{aligned}$$

Statement: The maximum possible initial acceleration of the person wearing dress shoes is 5.1 m/s^2 [forwards].

(b) When we substitute $F_{S_{max}} = \mu_S F_N$ into the equation $F_{net} = F_{S_{max}}$ and simplify, the mass of the person cancels out.

$$\begin{aligned} F_{net} &= F_{S_{max}} \\ ma &= \mu_S F_N \\ ma &= \mu_S mg \\ a &= \mu_S g \end{aligned}$$

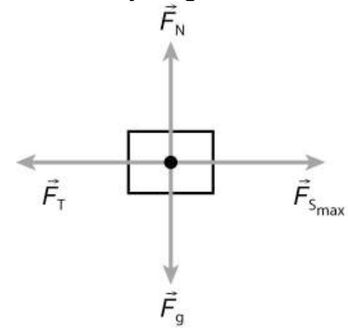
So we do not need the mass of either person when finding the maximum possible initial acceleration.

(c) The ratio of the two accelerations is:

$$\begin{aligned} \frac{a_1}{a_2} &= \frac{\mu_{S1} g}{\mu_{S2} g} \\ &= \frac{\mu_{S1}}{\mu_{S2}} \\ &= \frac{0.52}{0.66} \\ \frac{a_1}{a_2} &= 0.79 \end{aligned}$$

From the above calculation, the ratio of the two accelerations is equal to the ratio of the two coefficients of friction.

2. Draw a free body diagram of the off-ice person.



As the off-ice person overcomes the force of static friction in order to move ahead, the tension in the rope equals in magnitude to the static friction acting on the person.

Given: m_1 = 78 kg; μ_S = 0.65; m_2 = 58 kg

Required: a

Analysis: First calculate the tension in the rope using $F_T = F_{S_{max}} = \mu_S F_N$. When the skater starts to accelerate, $F_{net} = F_T$. Then use $F_{net} = m_2 a$ to calculate the acceleration.

Solution:

$$\begin{aligned} F_T &= F_{S_{max}} \\ &= \mu_S m_1 g \\ &= (0.65)(78\text{ kg})(9.8\text{ m/s}^2) \\ F_T &= 497\text{ N (one extra digit carried)} \end{aligned}$$

Calculate the magnitude of the acceleration.

$$\begin{aligned} F_{net} &= F_T \\ m_2 a &= 497\text{ N} \\ (58\text{ kg})a &= 497\text{ N} \\ a &= 8.6\text{ m/s}^2 \end{aligned}$$

Statement: The maximum possible acceleration of the skater is 8.6 m/s^2 [towards off-ice person].

Tutorial 3 Practice, page 177

1. (a) Given: m = 0.170 kg; $\vec{v}_1$ = 21.2 m/s [W]; μ_K = 0.005; Δd = 58.5 m

Required: v_2

Analysis: Consider the forces acting on the puck. The magnitude of the net force on the puck equals the force of kinetic friction. First calculate the acceleration using $F_{net} = ma$. Then use the equation $v_2^2 = v_1^2 + 2a\Delta d$ to calculate the final speed of the puck.

Solution:

$F_{net} = F_K$

$ma = \mu_K F_N$

$ma = \mu_K mg$

$a = \mu_K g$

$= (0.005)(9.8 \text{ m/s}^2)$

$a = 0.049 \text{ m/s}^2$

The acceleration of the puck is 0.049 m/s^2.

Next calculate the final speed of the puck.

$v_2^2 = v_1^2 + 2a\Delta d$

$v_2 = \sqrt{v_1^2 + 2a\Delta d}$

$= \sqrt{(-21.2 \text{ m/s})^2 + 2(-0.049 \text{ m/s}^2)(58.5 \text{ m})}$

$v_2 = 21.1 \text{ m/s}$

Statement: The speed of the puck after travelling 58.5 m is 21.1 m/s.

(b) Given: m = 0.170 kg; μ_K = 0.047;

$\vec{v}_1$ = 21.2 m/s [W];

$\vec{v}_2$ = 21.06 m/s [W] (one extra digit carried)

Required: Δd

Analysis: First calculate the acceleration as done in part (a). Then use the equation $v_2^2 = v_1^2 + 2a\Delta d$ to calculate the distance travelled.

Solution:

$F_{net} = F_K$

$ma = \mu_K F_N$

$ma = \mu_K mg$

$a = \mu_K g$

$= (0.047)(9.8 \text{ m/s}^2)$

$a = 0.461 \text{ m/s}^2$ (one extra digit carried)

The magnitude of the acceleration of the puck is 0.461 m/s^2.

Next calculate the distance travelled.

$v_2^2 = v_1^2 + 2a\Delta d$

$v_2^2 - v_1^2 = 2a\Delta d$

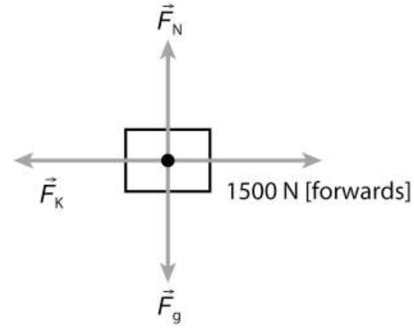
$\Delta d = \dfrac{v_2^2 - v_1^2}{2a}$

$= \dfrac{(-21.06 \text{ m/s})^2 - (-21.2 \text{ m/s})^2}{2(-0.461 \text{ m/s}^2)}$

$\Delta d = 6.42 \text{ m}$

Statement: The puck will travel 6.42 m for the same initial and final speeds.

2. Draw a FBD of the snowmobile.



Given: m_T = 320 kg + 120 kg + 140 kg = 580 kg; m_1 = 120 kg; m_2 = 140 kg; μ_K = 0.15; F_a = 1500 N [forwards]

Required: a

Analysis: First calculate the force of kinetic friction for the sleds using the equation $F_K = \mu_K F_N$. Then use the equation $F_{net} = m_T a$ to calculate the acceleration. Choose forwards as positive. So backwards is negative.

Solution:

$F_K = \mu_K F_N$

$= \mu_K (m_1 + m_2)g$

$= (0.15)(120 \text{ kg} + 140 \text{ kg})((9.8 \text{ m/s}^2)$

$F_K = 382 \text{ N}$ (one extra digit carried)

From the FBD of the snowmobile,

$\vec{F}_{net} = \vec{F}_a + \vec{F}_K$

$m_T a = +1500 \text{ N} + (-382 \text{ N})$

$(580 \text{ kg})a = +1118 \text{ N}$

$a = +1.9 \text{ m/s}^2$

$\vec{a} = 1.9 \text{ m/s}^2$ [forwards]

Statement: The acceleration of the snowmobile and the sleds is 1.9 m/s^2 [forwards].

3. (a) Given: m_1 = 3.2 kg; m_2 = 1.5 kg; μ_K = 0.30

Required: a

Analysis: First calculate the kinetic friction acting on the object on the table using $F_K = \mu_K F_N$. Then consider the magnitudes of the forces acting on each object to determine the acceleration.

Solution:

$F_K = \mu_K F_N$

$= \mu_K m_1 g$

$= (0.30)(3.2 \text{ kg})((9.8 \text{ m/s}^2)$

$F_K = 9.41 \text{ N}$ (one extra digit carried)

For the object on the table, the force of kinetic friction is in the opposite direction of motion.

$F_{net} = F_T - F_K$

$m_1a = F_T - 9.41\text{ N}$ (Equation 1)

For the hanging object, the tension acting is in the opposite direction of motion.

$F_{net} = F_g - F_T$

$m_2a = m_2g - F_T$ (Equation 2)

Add the equations to solve for a.

$$(m_1 + m_2)a = m_2g - 9.41\text{ N}$$
$$(4.7\text{ kg})a = (1.5\text{ kg})(9.8\text{ m/s}^2) - 9.41\text{ N}$$
$$a = 1.13\text{ m/s}^2$$
$$a = 1.1\text{ m/s}^2$$

Statement: The acceleration of the object on the table is 1.1 m/s^2 [right] and the acceleration of the hanging object is 1.1 m/s^2 [down].

(b) From equation 1,

$$m_1a = F_T - 9.41\text{ N}$$
$$F_T = m_1a + 9.41\text{ N}$$
$$= (3.2\text{ kg})(1.13\text{ m/s}^2) + 9.41\text{ N}$$
$$F_T = 13\text{ N}$$

The magnitude of the tension in the string is 13 N.

(c) Given: m_1 = 3.2 kg; a = 1.13 m/s^2 [right]; Δt = 1.2 s; $\vec{v}_1$ = 1.3 m/s [right]

Required: Δd

Analysis: Use the equation $\Delta d = v_i\Delta t + \frac{1}{2}a\Delta t^2$ to calculate the distance travelled.

Solution:

$$\Delta d = v_i\Delta t + \frac{1}{2}a\Delta t^2$$
$$= (+1.3\text{ m/s})(1.2\text{ s}) + \frac{1}{2}(+1.13\text{ m/s}^2)(1.2\text{ s})^2$$
$$\Delta d = 2.4\text{ m}$$

Statement: The objects will move 2.4 m in 1.2 s.

4. (a) Given: m = 125 kg; F_T = 350 N; a = 1.2 m/s^2 [forwards]

Required: μ_K

Analysis: First calculate the force of kinetic friction for the box using the equation $F_{net} = F_T + F_K$. Then use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate μ_K. Choose forwards as positive. So backwards is negative.

Solution:

$$\vec{F}_{net} = \vec{F}_T + \vec{F}_K$$
$$ma = +350\text{ N} + F_K$$
$$(125\text{ kg})(+1.2\text{ m/s}^2) = +350\text{ N} + F_K$$
$$F_K = -200\text{ N}$$
$$\vec{F}_K = 200\text{ [backwards]}$$

Use the magnitude of the kinetic friction to calculate μ_K.

$$\mu_S = \frac{F_K}{F_N}$$
$$= \frac{F_T}{mg}$$
$$= \frac{200\text{ N}}{(125\text{ kg})(9.8\text{ m/s}^2)}$$
$$\mu_S = 0.16$$

Statement: The coefficient of kinetic friction is 0.16.

(b) Given: a = 1.2 m/s^2 [forwards]; Δt = 5.0 s

Required: Δd

Analysis: Use the equation $\Delta d = v_i\Delta t + \frac{1}{2}a\Delta t^2$ to calculate the distance travelled.

Solution: Choose forwards as positive. So backwards is negative. Since the box starts its motion from rest, v_i = 0 m/s.

$$\Delta d = \frac{1}{2}a\Delta t^2$$
$$= \frac{1}{2}(+1.2\text{ m/s}^2)(5.0\text{ s})^2$$
$$\Delta d = 15\text{ m}$$

Statement: The box travels 15 m up to the moment the cable breaks.

(c) Given: a_1 = 1.2 m/s^2 [forwards]; Δt = 5.0 s

Required: Δd

Analysis: First use the equation $v_2 = v_1 + a\Delta t$ to calculate the velocity v_2 of the box just before the cable breaks. For the second part of the motion, the tension in the cable is zero. Use $F_{net} = F_K$ to calculate the acceleration of the box. Then use the equation $v_f^2 = v_i^2 + 2a\Delta d$ to calculate the distance travelled when the motion of the box stops. Choose forwards as positive. So backwards is negative.

Solution: For the first part of the motion, the initial velocity v_1 of the box is 0 m/s.

$$\begin{aligned}\vec{v}_2 &= \vec{a}_1\Delta t \\ &= (+1.2\text{ m/s}^2)(5.0\text{ s}) \\ &= +6.0\text{ m/s} \\ \vec{v}_2 &= 6.0\text{ m/s [forwards]}\end{aligned}$$

For the second part of the motion,

$$\begin{aligned}\vec{F}_{\text{net}} &= \vec{F}_{\text{K}} \\ ma_2 &= -200\text{ N} \\ (125\text{ kg})a_2 &= -200\text{ N} \\ a_2 &= \frac{-200\text{ N}}{125\text{ kg}} \\ &= -1.6\text{ m/s}^2 \\ \vec{a}_2 &= 1.6\text{ m/s}^2\text{ [backwards]}\end{aligned}$$

Now calculate the distance travelled. The initial velocity $\vec{v}_1$ is 6.0 m/s [forwards] and the final velocity $\vec{v}_f$ is 0 m/s.

$$\begin{aligned}v_f^2 &= v_i^2 + 2a\Delta d \\ 0 &= v_i^2 + 2a\Delta d \\ v_i^2 &= -2a\Delta d \\ \Delta d &= \frac{v_i^2}{-2a} \\ &= \frac{(+6.0\text{ m/s})^2}{-2(-1.6\text{ m/s}^2)} \\ \Delta d &= 11\text{ m}\end{aligned}$$

Statement: The box travels 11 m from the moment the cable breaks until it stops.

Section 4.3 Questions, page 178

1. (a) Given: m = 64 kg; μ_S = 0.72

Required: $F_{S_{max}}$

Analysis: $\mu_S = \frac{F_{S_{max}}}{F_N}$

Solution:

$$\begin{aligned}F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.72)(64\text{ kg})(9.8\text{ m/s}^2) \\ F_{S_{max}} &= 450\text{ N}\end{aligned}$$

Statement: The maximum force of static friction acting on the student is 450 N.

(b) Given: m = 250 kg; μ_S = 0.55

Required: $F_{S_{max}}$

Analysis: $\mu_S = \frac{F_{S_{max}}}{F_N}$

Solution:

$$\begin{aligned}F_{S_{max}} &= \mu_S F_N \\ &= \mu_S mg \\ &= (0.55)(250\text{ kg})(9.8\text{ m/s}^2) \\ F_{S_{max}} &= 1300\text{ N}\end{aligned}$$

Statement: The maximum force of static friction acting on the box is 1300 N.

(c) Answers may vary. Sample answer:
The competition is unfair. We know that the magnitude of the coefficient of friction is always less than one. The mass of the box of books is more than three times the average mass of a student. To provide a force large enough to move the box, you need a large coefficient of static friction. However, it is unlikely that the coefficient for the student's shoes on the floor to be more than three times that for the box.

2. (a) Given: m_1 = 55 kg; m_2 = 78 kg

Required: μ_S

Analysis: First calculate the maximum magnitude of the maximum force of static friction for the actor on ice. Since neither actor is moving, the net force on each is zero. For the hanging actor, $F_T = F_g = m_2 g$. For the actor on ice, $F_T = F_{S_{max}}$.

Then use $\mu_S = \frac{F_{S_{max}}}{F_N}$ to calculate μ_S.

Solution:

$$\begin{aligned}\mu_S &= \frac{F_{S_{max}}}{F_N} \\ &= \frac{m_2 g}{m_1 g} \\ &= \frac{m_2}{m_1} \\ &= \frac{78\text{ kg}}{55\text{ kg}} \\ \mu_S &= 1.4\end{aligned}$$

Statement: The minimum coefficient of static friction is 1.4.

(b) Answers may vary. Sample answer:
The answer is not reasonable since the coefficient of static friction is usually less than one. For an ice surface, the force of static friction is very low and so will be the coefficient of static friction (often around 0.1).

(c) Answers may vary. Sample answer:
To make the scene more realistic, make the value of μ_S less than one by switching the two actors. Change the ice shelf to a shelf with a rough surface that will give a greater value of static friction to stop the heavier actor from sliding.

3. (a) Given: m_T = 5.0 kg + 3.0 kg = 8.0 kg; $F_{S_{max}}$ = 31.4 N

Required: μ_S

Analysis: $\mu_S = \frac{F_{S_{max}}}{F_N}$

Solution:

$$\begin{aligned}\mu_S &= \frac{F_{S_{max}}}{F_N}\\ &= \frac{F_{S_{max}}}{m_T g}\\ &= \frac{31.4\text{ N}}{(8.0\text{ kg})(9.8\text{ m/s}^2)}\\ \mu_S &= 0.40\end{aligned}$$

Statement: The coefficient of static friction is 0.40.

(b) Consider forces acting on the second object. Since the net force is zero, the tension in the string equals the magnitude of the force of static friction.

$$\begin{aligned}F_T &= F_{S_{max}}\\ &= \mu_S F_N\\ &= \mu_S mg\\ &= (0.40)(3.0\text{ kg})(9.8\text{ m/s}^2)\\ F_T &= 12\text{ N}\end{aligned}$$

If the students pull on the first object, the magnitude of the tension in the string is 12 N.

(c) The maximum force of static friction is given by the equation $F_{S_{max}} = \mu_S F_N$. If the students push on the second object with 15.0 N [down], the total normal force becomes: $F_N = m_T g + 15.0\text{ N}$

$$\begin{aligned}F_{S_{max}} &= \mu_S F_N\\ &= \mu_S(m_T g + 15.0\text{ N})\\ &= (0.40)[(8.0\text{ kg})(9.8\text{ m/s}^2) + 15\text{ N}]\\ F_{S_{max}} &= 37\text{ N}\end{aligned}$$

So the magnitude of the maximum force of static friction is 37 N.

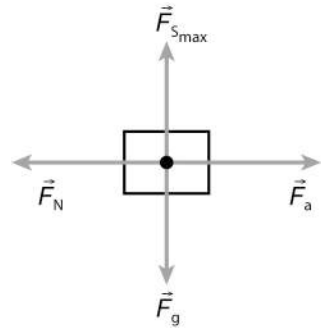
Since the net force is zero, the magnitude of the tension in the string equals the magnitude of the force of static friction on the second object.
In this case, $F_N = mg + 15.0\text{ N}$.

$$\begin{aligned}F_T &= F_{S_{max}}\\ &= \mu_S F_N\\ &= \mu_S mg\\ &= (0.40)[(3.0\text{ kg})(9.8\text{ m/s}^2) + 15.0\text{ N}]\\ F_T &= 18\text{ N}\end{aligned}$$

So the magnitude of the tension is 18 N.

(d) If the student pushes down on the 5.0 kg object in part (c), the total normal force is the same so the answer will not change. However, the normal force on the second object will not be the same. So the answer for the magnitude of the tension in the string will change.

4. (a) Draw a FDB of the book.



Since the book does not move, the net force on the book is zero.

Given: m_1 = 0.80 kg; F_N = 26 N

Required: μ_S

Analysis: Use the equation $\mu_S = \frac{F_{S_{max}}}{F_N}$ to calculate μ_S. In this case, $F_{S_{max}} = F_g = mg$

Solution:

$$\begin{aligned}\mu_S &= \frac{F_{S_{max}}}{F_N}\\ &= \frac{mg}{F_N}\\ &= \frac{(0.80\text{ kg})(9.8\text{ m/s}^2)}{26\text{ N}}\\ \mu_S &= 0.30\end{aligned}$$

Statement: The coefficient of static friction is 0.30.

(b) Answers may vary. Sample answer:
The student could add an object on top of the book or tie an object to the bottom of the book so that the magnitude of F_g is greater than the magnitude of $F_{S_{max}}$ to make the net force non-zero.

5. (a) Given: m_1 = 4.4 kg; μ_S = 0.42
Required: $F_{S_{max}}$
Analysis: $\mu_S = \dfrac{F_{S_{max}}}{F_N}$
Solution:
$$\begin{aligned} F_{S_{max}} &= \mu_S F_N \\ &= \mu_S m_1 g \\ &= (0.42)(4.4\text{ kg})(9.8\text{ m/s}^2) \\ &= 18.1\text{ N} \\ F_{S_{max}} &= 18\text{ N} \end{aligned}$$
Statement: The maximum force of static friction for the block is 18 N.

(b) Given: $F_{S_{max}}$ = 18.1 N; m_b = 0.12 kg; m_w = 0.02 kg
Required: n
Analysis: Since the block is not moving, the net force is zero. So $F_T = F_{S_{max}}$. For the bucket, $F_T = F_g = m_T g$. Use the equation $F_{S_{max}} = m_T g$ to calculate the total mass, m_T, of bucket and washers added. Then use the equation $m_T = m_b + nm_w$ to find n.
Solution:
$$\begin{aligned} F_{S_{max}} &= m_T g \\ m_T &= \frac{F_{S_{max}}}{g} \\ &= \frac{18.1\text{ N}}{9.8\text{ m/s}^2} \\ m_T &= 1.85\text{ kg (one extra digit carried)} \end{aligned}$$

Calculate the maximum number of washers added.
$$\begin{aligned} m_T &= m_b + nm_w \\ nm_w &= m_T - m_b \\ n &= \frac{m_T - m_b}{m_w} \\ &= \frac{1.85\text{ kg} - 0.12\text{ kg}}{0.02\text{ kg}} \\ n &= 86.5 \end{aligned}$$
Statement: The students can add 86 washers to the bucket without moving the block.

(c) Answers may vary. Sample answer:
This investigation may not yield accurate results if the students use it to find the coefficient of static friction. The number of washers added is a discrete quantity so the total mass m_T found could differ by a quantity of 0.02 kg. This difference will affect the accuracy of $F_{S_{max}}$ used to find the coefficient of static friction.

(d) Given: m_1 = 4.4 kg; μ_K = 0.34; m_T = 0.12 kg + 87(0.02 kg) = 1.86 kg;
Required: $\vec{a}$
Analysis: First calculate the kinetic friction acting on the block using $F_K = \mu_K F_N$. Then consider the magnitudes of the forces acting on the block and the bucket containing the washers to determine the acceleration.
Solution: First calculate the kinetic friction for the block.
$$\begin{aligned} F_K &= \mu_K F_N \\ &= \mu_K m_1 g \\ &= (0.34)(4.4\text{ kg})((9.8\text{ m/s}^2) \\ F_K &= 14.66\text{ N (two extra digits carried)} \end{aligned}$$

The force of kinetic friction is in the opposite direction of motion. For the block,
$$\begin{aligned} F_{net} &= F_T - F_K \\ m_1 a &= F_T - 14.66\text{ N (Equation 1)} \end{aligned}$$

For the bucket with the washers, the tension acting is in the opposite direction of motion.
$$\begin{aligned} F_{net} &= F_g - F_T \\ m_T a &= m_T g - F_T \text{ (Equation 2)} \end{aligned}$$

Add the equations to solve for a.
$$\begin{aligned} m_1 a + m_T a &= m_T g - 14.66\text{ N} \\ (m_1 + m_T)a &= m_T g - 14.66\text{ N} \\ (4.4\text{ kg} + 1.86\text{ kg})a &= (1.86\text{ kg})(9.8\text{ m/s}^2) - 14.66\text{ N} \\ a &= 0.57\text{ m/s}^2 \end{aligned}$$
Statement: The acceleration of the block when the 87th washer is added is 0.57 m/s^2 [right].

6. (a) Given: m_A = 6(65 kg) = 390 kg; $F_{S_{max}}$ = 3200 N
Required: μ_S
Analysis: $\mu_S = \dfrac{F_{S_{max}}}{F_N}$
Solution:
$$\begin{aligned} \mu_S &= \frac{F_{S_{max}}}{F_N} \\ &= \frac{F_{S_{max}}}{m_A g} \\ &= \frac{3200\text{ N}}{(390\text{ kg})(9.8\text{ m/s}^2)} \\ \mu_S &= 0.84 \end{aligned}$$
Statement: Team A's coefficient of static friction is 0.84.

(b) Given: m_A = 390 kg; F_K = 2900 N
Required: μ_K
Analysis: $\mu_K = \frac{F_K}{F_N}$
Solution:

$$\mu_K = \frac{F_K}{F_N} = \frac{F_K}{m_A g} = \frac{2900 \text{ N}}{(390 \text{ kg})(9.8 \text{ m/s}^2)}$$
$$\mu_K = 0.76$$

Statement: Team A's coefficient of kinetic friction is 0.76.

7. (a) Given: m = 260 kg; a = 0.30 m/s^2 [forwards]; F_a = (280 N + 340 N) [forwards] = 620 N [forwards]
Required: μ_K
Analysis: First find the force of kinetic friction for the piano using the equation $F_{net} = F_a + F_K$. Then use the equation $\mu_K = \frac{F_K}{F_N}$ to calculate μ_K. Choose forwards as positive. So backwards is negative.
Solution:

$$F_{net} = F_a + F_K$$
$$ma = +620 \text{ N} + F_K$$
$$(260 \text{ kg})((+0.30 \text{ m/s}^2) = +620 \text{ N} + F_K$$
$$F_K = -542 \text{ N}$$

Use the magnitude of the force of kinetic friction to calculate the coefficient of kinetic friction.

$$\mu_K = \frac{F_K}{F_N} = \frac{F_K}{mg} = \frac{542 \text{ N}}{(260 \text{ kg})(9.8 \text{ m/s}^2)}$$
$$\mu_K = 0.21$$

Statement: The coefficient of kinetic friction is 0.21.

(b) Given: m = 260 kg; $\vec{a}_1$ = 0.30 m/s^2 [forwards]; Δt_1 = 6.2 s
Required: Δt_2
Analysis: First use the equation $v_2 = v_1 + a\Delta t$ to calculate the velocity v_2 of the piano just before the students stop pushing. Use $F_{net} = F_K$ to calculate the new acceleration of the piano. Then use the equation $v_f = v_i + a\Delta t$ to calculate the time it takes the piano to stop moving. Choose forwards as positive. So backwards is negative.
Solution: When the students are pushing, the initial velocity v_1 of the box is 0 m/s.

$$\vec{v}_2 = \vec{a}_1 \Delta t_1$$
$$v_2 = \left(+0.30 \ \frac{\text{m}}{\text{s}^{\not 2}}\right)(6.2 \not\text{s})$$
$$v_2 = +1.86 \text{ m/s}$$
$$\vec{v}_2 = 1.86 \text{ m/s [forwards]}$$

When the students stop pushing,

$$F_{net} = F_K$$
$$ma_2 = -542 \text{ N}$$
$$(260 \text{ kg})a_2 = -542 \text{ N}$$
$$a_2 = \frac{-542 \text{ N}}{260 \text{ kg}}$$
$$a_2 = -2.08 \text{ m/s}^2 \text{ (one extra digit carried)}$$

Now use the new acceleration to calculate the time it takes the piano to stop moving. The initial velocity v_i is 1.86 m/s [forwards] and the final velocity v_f is 0 m/s.

$$v_f = v_i + a_2 \Delta t_2$$
$$0 = +1.86 \text{ m/s} + (-2.08 \text{ m/s}^2)\Delta t_2$$
$$\Delta t_2 = 0.89 \text{ s}$$

Statement: It will take the piano 0.89 s to stop moving.

8. (a) (i) Given: m = 65 kg; $\vec{F}_a$ = 250 N [forwards]; $\vec{F}_K$ = 62 N [backwards]
Required: $\vec{a}$
Analysis: Use the equation $\vec{F}_{net} = \vec{F}_a + \vec{F}_K$ to find the net force on the sprinter and use the equation $\vec{F}_{net} = m\vec{a}$ to calculate $\vec{a}$. Choose forwards as positive. So backwards is negative.
Solution:

$$\vec{F}_{net} = \vec{F}_a + \vec{F}_K$$
$$ma = +250 \text{ N} + (-62 \text{ N})$$
$$(65 \text{ kg})a = +188 \text{ N}$$
$$a = +2.89 \text{ m/s}^2$$
$$\vec{a} = 2.9 \text{ m/s}^2 \text{ [forwards]}$$

Statement: The acceleration of the sprinter is 2.9 m/s^2 [forwards].

(ii) Given: $\vec{a}$ = 2.89 m/s^2 [forwards]; Δt = 2.0 s
Required: Δd

Analysis: Use the equation $\Delta d = v_i \Delta t + \frac{1}{2} a \Delta t^2$ to calculate the distance travelled. Since the sprinter starts from rest, v_i = 0 m/s.
Solution:

$$\begin{aligned}\Delta d &= \frac{1}{2} a \Delta t^2 \\ &= \frac{1}{2}(+2.89\ \text{m/s}^2)(2.0\ \text{s})^2 \\ \Delta d &= 5.8\ \text{m}\end{aligned}$$

Statement: The distance travelled is 5.8 m.
(iii) Given: m = 65 kg; $F_{S_{max}}$ = 250 N

Required: μ_S

Analysis: $\mu_S = \frac{F_{S_{max}}}{F_N}$

Solution:

$$\begin{aligned}\mu_K &= \frac{F_{S_{max}}}{F_N} \\ &= \frac{F_{S_{max}}}{mg} \\ &= \frac{250\ \text{N}}{(65\ \text{kg})(9.8\ \text{m/s}^2)} \\ \mu_K &= 0.39\end{aligned}$$

Statement: The coefficient of friction between the sprinter's shoes and the track is 0.39.
(b) The friction applied on the sprinter from the ground is static friction. When the sprinter's shoes push backwards on the ground, the ground pushes back on the sprinter's feet with a reaction force equal in magnitude to the force that pushes the sprinter forwards. This force is the static friction that will start the sprinter moving from rest. Every time the sprinter pushes backwards on the ground, the ground provides this force to keep the sprinter moving. So this applied force is static friction.
9. Given: m = 15.0 kg; $\vec{v}_f$ = 1.2 m/s [forwards];

Δt = 2.0 s; μ_K = 0.25
Required: $\vec{F}_a$

Analysis: First use the equation $a = \frac{v_f - v_i}{\Delta t}$ to calculate the acceleration of the lawnmower and use the equation $F_K = \mu_K F_N$ to calculate the force of kinetic friction acting on it. Then use $F_{net} = ma$ and $F_{net} = F_a + F_K$ to calculate the applied force. Choose forwards as positive. So backwards is negative. Since the homeowner starts from rest, v_i = 0 m/s.
Solution:

$$\begin{aligned}a &= \frac{v_f - v_i}{\Delta t} \\ &= \frac{v_f}{\Delta t} \\ &= \frac{+1.2\ \text{m/s}}{2.0\ \text{s}} \\ a &= +0.60\ \text{m/s}^2\end{aligned}$$

Calculate the kinetic friction that acts in the opposite direction of motion.

$$\begin{aligned}F_K &= \mu_K F_N \\ &= \mu_K mg \\ &= (0.25)(15.0\ \text{kg})(9.8\ \text{m/s}^2) \\ F_K &= 36.75\ \text{N}\end{aligned}$$

Now calculate the applied force.

$$\begin{aligned}\vec{F}_{net} &= \vec{F}_a + \vec{F}_K \\ ma &= F_a + (-36.75\ \text{N}) \\ (15.0\ \text{kg})(+0.60\ \text{m/s}^2) &= F_a - 36.75\ \text{N} \\ F_a &= +46\ \text{N} \\ \vec{F}_a &= 46\ \text{N [forwards]}\end{aligned}$$

Statement: The horizontal applied force acting on the lawnmower is 46 N [forwards].
10. Given: m = 75 kg; v_i = 2.8 m/s [forwards]; Δd = 3.8 m
Required: μ_K
Analysis: First use the equation $v_f^2 = v_i^2 + 2a\Delta d$ to calculate the acceleration of the baseball player. Then use $F_{net} = F_a + F_K$ to calculate the force of kinetic friction and use $\mu_K = \frac{F_K}{F_N}$ to calculate μ_K.
Choose forwards as positive. So backwards is negative. Since the player slides to come to rest, v_f = 0 m/s.

Solution:

$$0 = v_i^2 + 2a\Delta d$$

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

$$= \frac{(+2.8 \text{ m/s})^2}{-2(3.8 \text{ m})}$$

$$a = -1.03 \text{ m/s}^2 \quad \text{(one extra digit carried)}$$

Since there is no applied force on the player,

$$F_{net} = F_K$$

$$ma = F_K$$

Now calculate μ_K.

$$\mu_K = \frac{F_K}{F_N}$$

$$= \frac{ma}{mg}$$

$$= \frac{a}{g}$$

$$= \frac{1.03 \cancel{\text{m/s}^2}}{9.8 \cancel{\text{m/s}^2}}$$

$$\mu_K = 0.11$$

Statement: The coefficient of kinetic friction is 0.11.

Section 4.4: Forces Applied to Automotive Technology

Section 4.4 Questions, page 183

1. (a) Tire Y is more likely to experience hydroplaning when driving on a wet road. Tire X has deeper treads so water can move through the grooves and pass through tire X more easily. Water in front of the tire Y may not pass through the tire quickly enough, causing the water level in front of the tire to increase. This water build-up in front of the tire can lead to hydroplaning.
(b) The magnitude of static friction acting on a tire on a road surface depends on the surface area of the tire that is in contact with the road. The greater the surface area, the greater the friction. As the surface area decreases during the transition stage of hydroplaning, the force of friction acting on the tire decreases.
2. Answers may vary. Sample answer:
The wear pattern on the low pressure tire reduces the tread area on the outer edges of the tire. As the tread area decreases, the number of grooves that provide pathways for water to pass through decreases. Hydroplaning will happen more easily. The wear pattern on the excess pressure tire reduces the tread area in the middle of the tire. On a wet road, the water in front of the tire may not pass along the sides of the tire quickly enough, causing hydroplaning.
3. When the driver starts to speed up on a wet road, the water in front of the tire may not have enough time to pass through the grooves toward the back of the tire. This causes the water level in front of the tire to increase. As the speed continues to increase, the water level in front of the tire increases. As the water level builds up, the tire will start to lose contact with the road surface. In this situation, the force of friction acting on the tires will reduce.
4. Answers may vary. Sample answer:
The rim brake on a bicycle uses a lever to squeeze the brake pads against the rim of the wheel to apply a normal force that provides a force of friction on the rim to slow down the wheel, and thus the bicycle. The disc brake on a car works similarly but it is a piston that squeezes the brake pads and the normal force is applied to a rotor with the force of friction acting on the rotor to slow down the wheel, and thus the car.
5. Answers may vary. Sample answers:
(a) By increasing the friction on the bicycle wheel, you can increase the amount of energy you need to exert to pedal the bicycle. The device does this by putting the bicycle in a certain gear.
(b) I would design a series of gear wheels that are engaged by a bicycle chain. A lever on top of the bicycle handle bars would position the chain on the appropriate gear wheel. When the smaller wheel is engaged, resistance is the greatest.
Diagrams may vary. Students should include a diagram that matches the description of the stationary bicycle above.
(c) To determine the relationship between the device setting and maximum force of static friction acting on a bicycle wheel, I would have a person sit on a bicycle set at a particular gear. The person would pedal the bicycle and rate the effort it took to pedal for 1 min. This is repeated for each gear. Comparing the pedalling effort by gear will determine the relationship between the two variables.
6. Answers may vary. Sample answer:
In disc brakes, a piston pushes the brake pads against a rotor. The harder the brake pads are squeezed, the greater is the normal force on the rotor, which in turn increases the force of friction acting on the rotor. According to Newton's second law, as the net force on the rotor decreases due to friction, the acceleration of the rotor (attached to the wheel) decreases. As a result, the motion of the wheel decreases, slowing down the car.
7. Answers may vary. Sample answer:
The statement is true. If there is no friction from the road on the tires, the car continues at the same speed. For example, when a driver tries to break while on ice, the tires can stop completely, but the car will continue to glide. When there is friction between the road and tires, a tire spinning slower decreases the distance the car travels per second.
8. Answers may vary. Sample answers:
(a) An ABS uses a computer to monitor the speed of the wheels of a car. A sudden large decrease in speed may cause a car to skid. In this situation, the computer can change the force on the brake pads rapidly, allowing the car to slow down as fast as possible, reducing the stopping distance without the tires skidding.
(b) The computer of an ABS can detect the speed of the wheels and change the force on the brake pads to adjust the friction on the wheels. This helps the driver steer the car even while applying firm pressure to the brake pedal.

9. Answers may vary. Sample answers:
(a) An ABS and traction control both make use of sensors and computer controls to increase the safety of a car. When a wheel experiences a sudden decrease in speed, the computer of an ABS will quickly reduce the force on the brake pads until the wheel moves at an acceptable speed. Traction control is the reverse of an ABS. When a vehicle speeds up and the wheels turn faster than the car is moving, the tires will start sliding. The sensor sends this message to a computer that decreases the amount of fuel to the engine to slow down the wheels.
(b) When a car is experiencing understeering (force of friction on the front wheels is not enough to prevent the car from travelling in a straight line while the driver is making a turn) or oversteering (the car turns more than the driver intended and the back wheels start to slide sideways, spinning the car around), the ESC comes into play. An ESC can activate one or more brakes using an ABS to slow down the car or adjust the speed of the car using traction control.
10. Crumple zones in a car are designed to crush during an accident. The crushing action increases the time it takes to stop the car, reducing the acceleration of the occupants and the force acting on them. As a result, the occupants are more likely to survive the accident uninjured.
11. One of the safety innovations is a pretensioner. The pretensioner pulls in on the seat belt when a computer detects a crash. During a sudden stop, the seat belt is reeled in to keep a person in the optimal crash position in the seat, reducing the force acting on the person. Another seat belt safety innovation is a load limiter. A fold is sewn in the belt material. When a person in an accident is pushed forwards on the seat belt with a large force, the stitching breaks to give the belt a greater length, decreasing the force acting on the person.
12. (a) An airbag is a thin nylon bag folded into a car steering wheel or dashboard. It has a sensor that inflates the bag when a collision is detected to protect occupants of the vehicle.
(b) An airbag rapidly inflates and pushes out at a speed high enough to stop a driver or passenger from moving forwards when a car comes to a sudden stop.
(c) With a deployed airbag, the person collides with the airbag instead of the dashboard or steering wheel. As the person collides with an airbag, it compresses. This increases the time of collision, which further reduces the force acting on the person.
13. Answers may vary. Sample answer:
The Uniform Tire Quality Grading rating is made up of three components. The tread wear grade is a comparative rating based on the wear rate of the tire when tested under controlled conditions on a specified test track. A tire graded 200 would wear twice as long under specified test conditions as one graded 100. Tire traction grades, from highest to lowest, are AA, A, B, and C. They represent the tire's ability to stop on wet pavement as measured under controlled conditions on specified test surfaces of asphalt and concrete. The testing does not take into account cornering, hydroplaning, or acceleration. The higher the grade, the shorter the stopping distance on wet pavement. The temperature grades, from highest to lowest, are A, B, and C. These represent the tire's resistance to the generation of heat.

Section 4.5: Forces Applied to Sports and Research

Section 4.5 Questions, page 188

1. (a) In the case of a spike in volleyball or hitting a golf ball, the player must use good technique to hit the ball as fast as possible.

(b) In the case of a slapshot in hockey or striking a golf ball, the player raises the stick and makes a powerful swing to hit the puck or ball to move it as quickly as possible in the intended direction.

2. (a) The sweet spot of a baseball bat is the point on the bat where most power can be generated. This implies that the ball will travel the farthest distance after the swing if it strikes the bat on the sweet spot.

(b) Answers may vary. Sample answer:
When a batter hits a ball, the bat will rebound from the force of the collision. If the ball is hit closer to the handle end, a straight-line force will occur at the pivot point. If the ball is hit nearer to the barrel end, a rotational force will occur at the handle end, causing the handle to move away from the batter. If the ball impacts at the sweet spot, these two opposite forces will balance, causing a net force of zero.

3. In the photograph of a typical swing, the golfer shows good technique as he is making the club head move really fast. The faster the club head is moving when it strikes the ball, the farther the ball can travel.

4. (a) Physicists now know that the thin layer of slushy water exists when the ice is exactly 0 °C. When the ice is cooled, this layer gets thinner and disappears when the temperature is –250 °C.

(b) Skate blades are now made slightly curved at the bottom so that they can dig into the ice, which in turn provides a normal force that pushes the skater forwards.

(c) The slushy water on ice at 0 °C reduces the coefficient of kinetic friction of a skate blade on ice to as low as 0.005. At extremely cold temperatures, this layer does not exist. The coefficient of kinetic friction of a steel skate blade on ice becomes 0.6, which means that the blade can no longer slide easily.

5. Answers may vary. Sample answers:

(a) When the skate blade is heated, it melts the ice below, forming a thin layer of slushy water that reduces the friction of the blade on the ice.

(b) The insertion of a battery into the hollow plastic is a disadvantage as the temperature of the blade, or the speed of the blade, is now electricity based and the skater will not be in full control of the performance of the blade using her skills or techniques.

(c) Therma Blade is designed to maintain a consistent temperature of approximately 5 °C using a small battery and a microprocessor stored within each skate blade holder. The warm blade increases the thickness of the slushy water layer between the blade and the ice, reducing the kinetic friction of sliding and the static friction at the start of the skating motion for skaters. The blade is still being tested and will be tested by a group of NHL hockey players during NHL game conditions. The advantages of the blade are that the reduced friction allows players to reach top speed faster and to skate using less energy, resulting in less fatigue over the course of a hockey game. The disadvantage of this blade is that it is battery-powered, making the performance of a player dependent on the battery providing the right temperature. What if the battery fails to warm up the blade during a hockey game?

(d) I do not think the Therma Blade should be allowed in hockey leagues across Canada. In these games, hockey players are using their skills and techniques. Relying on battery power to increase their speeds should not be recommended.

6. Answers may vary. Sample answer:
To move large blocks of stones, ancient Egyptians had to find ways to overcome the strong force of friction between the stone and the ground. The use of rolling logs allowed the two surfaces to be separated. Since the friction between the rolling logs and the stones and that between the rolling logs and the ground are much smaller, the stone blocks could be moved more easily. The rolling element bearing does a similar task. It uses the same principle to reduce the friction between two surfaces that slide or roll across each other.

7. Answers may vary. Sample answers:

(a) A typical fluid bearing separates two surfaces using a fluid to reduce the friction between surfaces.

(b) A thin layer of fluid that reduces the friction between two sliding or rolling surfaces is similar to the thin layer of slushy water formed between the skate blade and the ice surface. A fluid bearing requires a seal or pump to keep the fluid in place between the two surfaces in contact whereas the layer of slushy water that reduces the friction between the blade and ice comes from the melted ice when the skater digs the blade into the ice.

8. (a) Magnetic bearings use magnetic fields, instead of rolling elements or fluids, to keep two surfaces separated.

(b) Answers may vary. Sample answer:
One disadvantage of magnetic bearings over rolling element bearings is that electricity is required to operate the electromagnets so a back-up bearing system is needed. Another disadvantage is that magnetic bearings require electric energy to keep them working, whereas rolling element bearings do not.

9. Answers may vary. Sample answers:

(a) Some of the reasons why people with artificial limbs should be allowed and encouraged to complete with athletes in the Olympics and in other sports events are as follows. Disabled people should be given the chance, or the right, to compete with other people in events that are supposed to be open for all people. Participating in the Olympics is the dream for most athletes so this should also be made the dream for disabled athletes. Allowing people with artificial limbs to participate in events that disabled people normally could not participate in will make these people feel that with hard work and strong will, they can always make their dreams come true.

(b) Professional athletes using artificial limbs should not be allowed to compete with athletes that do not use these limbs. As technology improves, artificial limbs can continuously be made of materials that are lighter, more durable, and more flexible than before. With appropriate design, an artificial limb could be much lighter and stronger than a human leg. This might allow an athlete to run faster and for a longer time without getting exhausted, giving the athlete an unfair advantage over other athletes that do not use artificial limbs.

10. Answers may vary.

(a) Students' answers should include new advances in prostheses other than those mentioned in this unit.

(b) Students' answers should include the benefits of prostheses to people who have lost parts of their body, how government can get involved in the expensive research and the body part replacement with training for its operation, and some legislations that should be passed about insurance plans or health benefits for the users.

11. Answers may vary. Sample answer:
When a person sits, the hip has to support the upper body's weight and the hip slides quite often on different seat surfaces. So the material used in hip replacement must be strong, flexible but sturdy, wear resistant, and durable to function properly and last a long time.

12. Answers may vary. Sample answer:
Near-frictionless carbon is a solid material that can resist wear and has a very low coefficient of friction of 0.001. Due to these properties, near-frictionless carbon can be applied to different surfaces of the parts in machines to reduce the need for repair and replacement. Its application in the space program and aircraft design is being researched. In the future, the technology of using near-frictionless carbon for coating surfaces may eventually be inexpensive enough to be applied to cars or household items.

Chapter 4 Investigations

Investigation 4.1.1: Acceleration Due to Gravity and Terminal Speed, pages 191–192

Analyze and Evaluate

(a) The acceleration due to gravity for the 50 g object was 9.8 m/s^2. The acceleration due to gravity for the 100 g object was 9.8 m/s^2. The resultant acceleration due to gravity and air resistance for the coffee filter was 1.0 m/s^2. The only factor that affects the acceleration due to gravity is surface area. The coffee filter had a different acceleration because it experienced a lot of air resistance.

(b) The relationship between mass and surface area of a falling object and its average acceleration were tested.

(c) $a = \frac{v}{t}$ For the 50 g object:

$$a = \frac{\left(\frac{1.22\text{ m}}{0.50\text{ s}}\right)}{0.25\text{ s}}$$

$$a = 9.8\text{ m/s}^2$$

For the 100 g object:

$$a = \frac{\left(\frac{1.22\text{ m}}{0.50\text{ s}}\right)}{0.25\text{ s}}$$

$$a = 9.8\text{ m/s}^2$$

For the 2 g coffee filter:

$$a = \frac{\left(\frac{1.22\text{ m}}{1.56\text{ s}}\right)}{0.78\text{ s}}$$

$$a = 1.0\text{ m/s}^2$$

The greater the mass of an object, the greater the acceleration due to gravity and air friction. The acceleration that is specifically due to gravity does not change.

(d) The motion of the falling coffee filter was different from the other objects. The coffee filter has the most surface area, and so the largest force of resistance. This large air resistance will counteract the force of gravity, and the coffee filter's acceleration will be the slowest of the three objects.

(e) Answers may vary. Sample answer:
Some possible sources of error are the measurement of the objects' masses may not have been accurate. There could have been air currents in the room that affected the motion and velocity of the coffee filter. The objects may not have been dropped from exactly the same height or straight down. Also, if ticker tape was used, friction between the tape and the holder could slow the motion of the object. To reduce these errors, measure the objects before starting the investigation. Make sure there are no drafts in the testing room or drop the objects in a smaller space such as a box. Practise dropping the objects straight down before starting the investigation. If using ticker tape, ensure that the ticker tape is able to fall smoothly through its holder.

(f) I hypothesized that the greater the surface area of a falling object, the smaller its acceleration due to gravity and air resistance. I also hypothesized that the mass of a falling object did not affect its acceleration due to gravity. I was correct.

Apply and Extend

(g) The velocity-time graph for an object in free fall for an extended period of time would begin as a straight line with a negative slope. Over time, the velocity would level out at terminal velocity. The intercept would be 0 m/s at 0 s. The slope at the beginning is equal to the acceleration due to gravity, –9.8 m/s^2.
The velocity–time graph levels out because at high speeds, the air resistance increases and finally matches the acceleration. When the air resistance equals the acceleration due to gravity, the object reaches terminal velocity.

(h) If the mass of a falling object were increased, but its cross-sectional area stayed the same, the terminal speed of the object would be greater because the larger mass creates a larger gravitational force acting on the object.
The cross-sectional area of the object increased but the mass of the object stayed the same, the terminal speed would be less because the greater cross-sectional area causes greater air resistance.

Investigation 4.2.1: Factors That Affect Friction, page 193

Analyze and Evaluate

Answers may vary. Sample answers:

(a) • As the mass of an object increases, the magnitude of the friction acting on the object increases.

• As the size of the contact area of an object increases, the magnitude of the force acting on the object remains relatively the same.

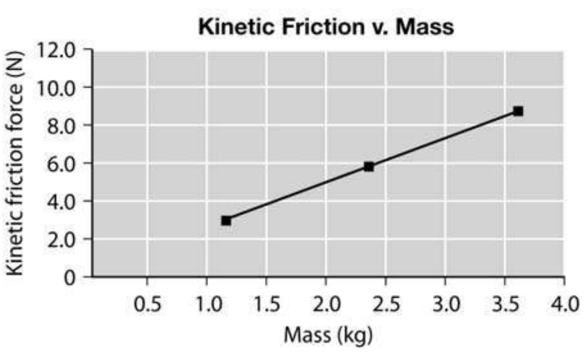
• The smoothness of the contact area of an object contacts does not seem to affect the magnitude of the force acting on the object.

• The type of materials in contact with each other does affect the magnitude of the force acting on the object.

(b) In this experiment, the relationships between static friction and mass, kinetic friction and mass, static friction and surface area, static friction and surface texture were tested.

(c) The value of $F_{S_{max}}$ was greater than the value of F_K when testing against the different variables.

(d)



As the mass of an object increases, the kinetic friction force increases.

The same relationship exists between the mass of an object and the static friction force.

(e) No, the values of $F_{S_{max}}$ and F_K did not change significantly when the size of the contact area of the object changed. This was also true when the type of material of the object or the smoothness of the surface area was changed.

(f) Some possible sources of error are not keeping the string level when pulling the object, the object might have been accelerated rather than pulled at a constant velocity, and the masses of the objects might not have been correctly measured.

To reduce these sources of error, a pulley system could have been attached to the object rather than just the string, the motor could have been used to pull the string so the velocity would be constant, and masses of smaller increments could have been used to make sure the mass of the object were more accurate.

(g) Answers may vary. Sample answer:

I was correct in my hypothesis that as the mass of an object increases, so does the force of friction.

I was not correct in my hypothesis that as the size of an object's contact area with a surface increased, the so too would the force of friction.

I was not correct in my hypothesis that smoother objects would have lower forces of friction.

Apply and Extend

(h) You should use the greatest force required to start an object moving to measure $F_{S_{max}}$ because all surfaces have tiny bumps and ridges. The bumps and ridges of an object in motion catch on the bumps and ridges of the surface it is in contact with. If you try to slide an object over a surface, a small amount of force will result in no motion. The force of friction is greater than the applied force. This is static friction. If you apply a little more force, the object "breaks free" and slides, although you still need to apply force to keep the object sliding. This is kinetic friction. You do not need to apply quite as much force to keep the object sliding as you needed originally to break free of static friction which is why you use the greatest force to measure $F_{S_{max}}$.

(i) According to Newton's Third Law of Motion, for every action there is an equal and opposite reaction. The force needed to pull the object will be met by an equal but opposite force by the sensor. So the force measured by the sensor is equal to F_K.

(j) It is better to use the average force reading for F_K due to the possible sources of error, such as inconsistent tension in the string pulling the object.

(k) In this experiment, it is important to repeat measurements several times for each factor and use the average values rather than a single measurement because of possible sources of error, such as uneven surface areas of the object and surface the object is pulled over, inconsistent force used to drag the object so that the velocity was not constant, and the fact that it is difficult to measure the when static friction ends and kinetic friction begins.

Investigation 4.2.2: Coefficients of Friction, page 194

Analyze and Evaluate

Answers may vary. Sample answer:

(a) The roughness of a surface affects the coefficient of kinetic friction more than for static friction. When the wood was tested against plastic and counter top surfaces, the coefficients of static friction were relatively the same. However, the coefficient of kinetic friction was slightly higher for plastic than melamine.

(b) The relationship between force of friction (static and kinetic) and type of surface was tested.

(c) For a plastic surface:

$F_{S_{max}} = 3.17$ N; $F_K = 2.87$ N

$\mu_S = 0.273$; $\mu_K = 0.247$

For a counter top surface:

$F_{S_{max}} = 3.70$ N; $F_K = 2.57$ N

$\mu_S = 0.287$; $\mu_K = 0.199$

For the rougher surface (counter top), the difference between the coefficients of static and kinetic friction was greater.

(d) Yes, the coefficient of static friction was less on the plastic surface and the coefficient of kinetic friction was greater on the plastic surface.

(e) One possible sources of error is not pulling the sensor with even tension so that the object might have been accelerated rather than pulled at a constant velocity. Another possible source of error is using a surface area that was not free of debris. Also, using a sensor that might not have been calibrated correctly would cause errors in measurement.

To reduce these sources of error, a pulley system could have been attached to the sensor and the object. Alternatively, a motor could have been used to pull the sensor so the velocity would be constant. To reduce error due to sensors, I could test several sensors and then calibrating the sensor used, or I could use multiple sensors and average the results.

(f) I hypothesized that the rougher the surface, the greater the coefficients of static and kinetic friction. I was only partly right.

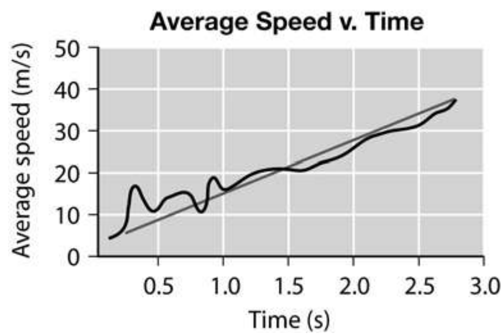
Apply and Extend

(g) It would not make sense if a student calculated a coefficient of kinetic friction greater than the coefficient of static friction. The coefficient of kinetic friction should be less than the coefficient of static friction because you require a smaller applied force to keep an object moving relative to the force needed to start it moving.

Investigation 4.3.1: Predicting Motion with Friction, page 195

Analyze and Evaluate

(a) I graphed the data and drew a line of best fit through the points. To find the average acceleration of the system, I calculated the slope of the line of best fit.



$$
\begin{aligned}
a &= \frac{\Delta v}{\Delta t} \\
&= \frac{20.00 \text{ cm/s} - 5.50 \text{ cm/s}}{1.25 \text{ s} - 0.05 \text{ s}} \\
&= \frac{14.50 \text{ cm/s}}{1.20 \text{ s}} \\
&= 12.08 \text{ cm/s}^2 \\
a &= 0.121 \text{ m/s}^2
\end{aligned}
$$

(b) The predicted value from step 4 of the Procedure was 0.133 m/s^2.

$$
\begin{aligned}
\text{percentage error} &= \frac{\text{measured value} - \text{predicted value}}{\text{predicted value}} \times 100\ \% \\
&= \frac{0.121 \text{ m/s}^2 - 0.133 \text{ m/s}^2}{0.133 \text{ m/s}^2} \times 100\ \% \\
&= -9.0\ \%
\end{aligned}
$$

The percentage error was 9.0 % less than the predicted value.

(c) Answers may vary. Sample answer:
The greatest source of error is in measuring the coefficients of friction. If a spring scale is used, you need to exercise extreme care or the theoretical and experimental values for acceleration will have large differences. To reduce this source of error, practice using the sensor before the investigation should be carried out.

Apply and Extend

(d) When another block of wood is added to the original one, the acceleration of the system would decrease because you are increasing the mass of the object being pulled across the horizontal surface. The force of friction increases.
When you increase the mass that is hanging from the string, you increase the acceleration of the system because the force of gravity on the mass is increased.

Chapter 4 Review, pages 198–203

Knowledge

1. (c)
2. (b)
3. (a)
4. (d)
5. (a)
6. (b)
7. (d)
8. (c)
9. (c)
10. (d)
11. (c)
12. (a) (iii)
(b) (i)
(c) (iv)
(d) (ii)
13. A force field is a region of space surrounding an object that can exert a force on other objects that are placed within that region and are able to interact with that force.
14. (a) Weight represents a force.
(b) Mass does not depend on gravity.
15. Static friction is a type of friction that prevents two surfaces from sliding relative to one another.
16. Kinetic friction replaces static friction.
17. A car's braking system utilizes static friction between the turning wheels and the ground below. This is a net force increase because other horizontal forces acting on the car are small compared to the friction force of the wheels. As static friction is applied to the road, the net force on the car is increased, thereby decreasing the car's speed.
18. (a) An antilock braking system and electronic traction control are systems that combine sensors and controls to increase the safety of a car. They both intermittently adjust the car's controls to decrease the amount of time the car slides instead of grips the road. The difference between the two systems is that an ABS applies its control to the braking system to prevent sliding while the car is slowing down, but electronic traction control applies its control during a car's acceleration to keep the car from over-accelerating and losing traction.
(b) By combining an ABS and electronic traction control, an ESC system prevents the car from losing its traction while accelerating and slowing down, ensuring safety during the car's operation.

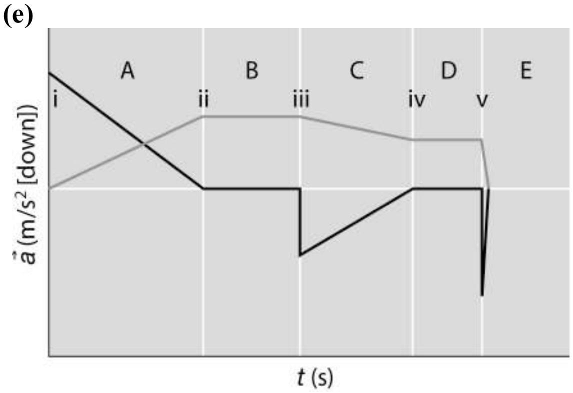
Understanding

19. (a) If they both hit the ground at the same time, the object with the greater mass has a larger cross-sectional area.
(b) If they have the same cross-sectional area, the object with the greater mass will hit the ground first.
(c) If both objects were dropped in a vacuum, where there is no air resistance, they would hit the ground at the same time.
20. (a) The force of gravity and air resistance are the two forces acting on a ball dropped through the air.
(b) As the ball is initially dropped, the force of gravity acts more strongly.
(c) As the ball moves at terminal speed, the force of gravity and air resistance are equal in magnitude and acting in opposite directions.
(d) At terminal speed:

$$\begin{aligned} F_f &= F_g \\ &= mg \\ &= (25 \text{ kg})(9.8 \text{ m/s}^2) \\ F_f &= 250 \text{ N} \end{aligned}$$

The magnitude of the friction force is 250 N.
21. (a) Interval A: The skydiver jumps out of the plane. Gravity is greater than air resistance.
Interval B: The skydiver has reached terminal speed without the parachute deployed. Gravity and air resistance are equal.
Interval C: The skydiver has deployed her parachute. Gravity is less than air resistance.
Interval D: The skydiver has reached terminal speed with the parachute deployed. Gravity and air resistance are equal.
Interval E: The skydiver has reached the ground. Gravity equals normal force.
(b) The skydiver reaches maximum speed throughout interval B.
(c) The force of air resistance is greatest at the beginning of interval C.
(d) The skydiver is travelling at terminal speed throughout interval B (parachute not deployed) and interval D (parachute deployed).

(e)



22. (a) The slowing of a skydiver after the deployment of the parachute indicates that the gravitational force is less than the air resistance.
(b) As the skydiver slows towards terminal speed, the air resistance decreases until its magnitude equals that of the gravitational force.
23. The magnitudes of the gravitational field strength and the gravitational acceleration at Earth's surface are both 9.8 m/s^2.
24. (a) Answers may vary. Sample answer:
One way to measure gravitational field strength is to measure the weight of a known mass and divide the weight by the mass. A second way is to measure the acceleration of an object falling from a known height.
(b) Use the equation $F_g = mg$ to determine g.

$$F_g = mg$$
$$g = \frac{F_g}{m} = \frac{14.67\text{ N}}{1.50\text{ kg}}$$
$$g = 9.78\text{ N/kg}$$

The gravitational field strength at that altitude is 9.78 N/kg.
(c) This altitude is likely above sea level because the gravitational field strength is less than that at sea level.
25. (a) The object will have the greatest weight at the North Pole.
(b) The object will have the least weight at the peak of Mount Everest.
(c)

Location	Weight
North Pole	124.74 N
equator	124.09 N
Mount Everest	123.88 N

26. (a) Mass is the quantity of matter in an object.
(b) It is possible to change the mass of an object by adding or removing material from that object.
(c) Weight is a measure of the force of gravity acting on an object.
(d) To change the weight of an object, but not the mass, move the object to a location with a different gravitational field strength.
(e) The magnitudes of an object's mass and weight will be equal when the gravitational field strength equals 1 N/kg.
27. (a) The terms "weightlessness" and "microgravity" are misapplied when discussing astronauts aboard the International Space Station because the astronauts and the space station are both experiencing a large force of gravity towards Earth's centre.
(b) The appropriate term to describe the state that makes them appear to float within the space station is that they are both experiencing free fall.
28. Choose up as positive. So down is negative. Determine the force of gravity acting on the person.

$$F_g = mg = (60.0\text{ kg})(-9.8\text{ m/s}^2)$$
$$F_g = -588\text{ N}$$

Then determine the normal force of the person.

$$F_{net} = F_g + F_N$$
$$ma = -588\text{ N} + F_N$$
$$(60.0\text{ kg})(-1.6\text{ m/s}^2) = -588\text{ N} + F_N$$
$$F_N = +490\text{ N}$$

The reading on the scale is 490 N.
29. Choose up as positive. So down is negative.
(a) Since the person is moving at a constant velocity, the net force is zero.

$$F_N + F_g = 0$$
$$F_N = -F_g$$

The reading on the scale is 58 kg.
(b) Calculate the normal force of the person accelerating at 2.7 m/s^2 [up].

$$F_{net} = F_g + F_N$$
$$ma = mg + F_N$$
$$(58\text{ kg})(+2.7\text{ m/s}^2) = (58\text{ kg})(-9.8\text{ m/s}^2) + F_N$$
$$F_N = 725\text{ N}$$

Divide the normal force by 9.8 m/s^2 to find the reading on the scale.

$$\frac{725\text{ N}}{9.8\text{ m/s}^2} = 74\text{ kg}$$

The reading on the scale is 74 kg.

(c) Calculate the normal force of the person accelerating at 3.8 m/s² [down].

$$F_{net} = F_g + F_N$$
$$ma = mg + F_N$$
$$(58\text{ kg})(-3.8\text{ m/s}^2) = (58\text{ kg})(-9.8\text{ m/s}^2) + F_N$$
$$F_N = 348\text{ N}$$

Divide the normal force by 9.8 m/s² to find the reading on the scale.

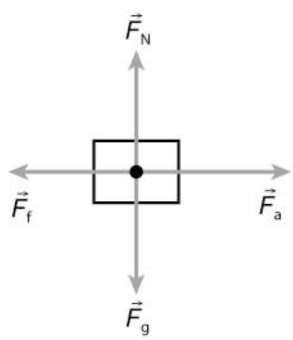
$$\frac{348\text{ N}}{9.8\text{ m/s}^2} = 36\text{ kg}$$

The reading on the scale is 36 kg.

30. Static friction prevents two stationary surfaces from sliding relative to each other, whereas kinetic friction is exerted by one surface on another when the two surfaces are sliding relative to each other.

31. (a) The force of gravity, the normal force, the applied force, and static friction are acting on the box.

(b)



(c) Consider the magnitude of the vertical forces on the box.

$$F_N = F_g$$
$$= mg$$
$$= (7.5\text{ kg})(9.8\text{ m/s}^2)$$
$$F_N = 74\text{ N}$$

The normal force acting on the box at sea level is 74 N.

32. (a) If the object is slowing, F_a is less than F_f.

(b) If the object travels at a constant velocity, F_a is equal to F_f.

(c) If the object is speeding up, F_a is greater than F_f.

33. (a) Divide the friction force by the normal force.

$$\mu = \frac{F_f}{F_N}$$
$$= \frac{6.6\text{ N}}{30.0\text{ N}}$$
$$\mu = 0.22$$

The coefficient of friction is 0.22.

(b) The object is not moving because the value of the coefficient of friction is high enough that it is more likely to be a coefficient of static friction than kinetic friction.

34. (a) To make the steel block start sliding across the horizontal surface, a force equal in magnitude to the force of static friction is required.

$$F_{S_{max}} = \mu_S F_N$$
$$= (0.78)(15\text{ N})$$
$$F_{S_{max}} = 12\text{ N}$$

The force required is 12 N.

(b) To maintain the steel block sliding at a constant speed, a force equal in magnitude to the force of kinetic friction is required.

$$F_K = \mu_K F_N$$
$$= (0.42)(15\text{ N})$$
$$F_K = 6.3\text{ N}$$

The force required is 6.3 N.

35. Answers may vary.

(a) Students' answers should describe any two objects that come in contact with one another but do not move due to friction. Sample answer: When sitting in a chair, static friction prevents me from sliding off.

(b) Students' answers should describe any two objects that slide against each other. Sample answer: When sliding with socks on a slippery floor, kinetic friction stops me from sliding forever.

(c) Students' answers should explain how the friction in each example in part (a) and part (b) helps something move or stops it from moving. Sample answer: In part (a), static friction helps a person sitting in a chair from moving out of a chair. In part (b), kinetic friction helps stop a person from continuously sliding on the floor.

36. Use the equations $F_f = F_K = \mu_K F_N$ and $F_{net} = ma$ to determine the applied force F_a.

$$F_{net} = F_a - F_f$$
$$ma = F_a - \mu_K F_N$$
$$ma = F_a - \mu_K mg$$
$$(4.4 \text{ kg})(1.5 \text{ m/s}^2) = F_a - (0.25)(4.4 \text{ kg})(9.8 \text{ m/s}^2)$$
$$F_a = 17 \text{ N}$$

The magnitude of the horizontal force being applied to move the object is 17 N.

37. (a) Use the equation $F_f = \mu_S F_N$ to determine the force F_a required. Since the couch is not moving, $F_{net} = 0$.

$$F_{net} = F_a - F_f$$
$$0 = F_a - \mu_S F_N$$
$$F_a = \mu_S F_N$$
$$= \mu_S F_g$$
$$= (0.31)(620 \text{ N})$$
$$F_a = 190 \text{ N}$$

The maximum force required to set the couch in motion is 190 N.

(b) Use the equation $F_f = \mu_K F_N$ to determine the force F_a required. Since the couch is moving at a constant speed, $F_{net} = 0$.

$$F_{net} = F_a - F_f$$
$$0 = F_a - \mu_K F_N$$
$$F_a = \mu_K F_N$$
$$= \mu_K F_g$$
$$= (0.21)(620 \text{ N})$$
$$F_a = 130 \text{ N}$$

The force required to maintain the couch moving at a constant speed is 130 N.

38. Use the equation $F_f = \mu_S F_N$ to determine the maximum coefficient of static friction μ_S required. At the start of the motion, $F_{net} = 0$.

$$F_{net} = F_a - F_f$$
$$0 = F_a - \mu_S F_N$$
$$F_a = \mu_S F_N$$
$$F_a = \mu_S mg$$
$$\mu_S = \frac{F_a}{mg}$$
$$= \frac{18 \text{ N}}{(2.7 \text{ kg})(9.8 \text{ m/s}^2)}$$
$$\mu_S = 0.68$$

The maximum coefficient of static friction between the brick and the wood is 0.68.

39. (a) Rubber is an exception to the concept that static friction and kinetic friction acting on an object is independent of the surface area in contact with another surface.

(b) This difference affects the design of car tires in that tires requiring more friction are made with an increased surface area. An example of this can be found on the wide tires used on race cars.

40. Answers may vary. Sample answer:
When the driver starts to speed up on a wet road, the water in front of the tire moves through the grooves and is squeezed out at the back of the tire. If the speed continues to increase, the water might not have enough time to pass through the grooves. The water level in front of the tire will increase, causing the tire to lose contact with the road surface. This hydroplaning stage is dangerous as the driver may lose control and not be able to stop the car due to the very low friction acting on the tires.

41. (a) The friction force is applied to the rotor attached to a wheel.

(b) The rotor experiences a friction force by coming into contact with the brake pads.

42. Crumple zones in a car's body and frame increases the distance travelled by the car when a collision occurs. This decreases the magnitude of acceleration experienced, thereby decreasing the force felt by the car's passengers.

43. When the force of the club's swing is greater than the friction force between golfer's hand and the golf club, the golf club will fly out of the golfer's hand. Golf club manufacturers use materials with high coefficient of static friction, such as rubber and leather, to make grips to increase the friction force on the golfer's hand.

44. (a) Roller bearings and ball bearings have been used for years to reduce wear and friction.

(b) Fluid bearings using a film or fluid are a newer type of bearing that reduces friction to negligible levels.

(c) Magnetic levitation systems reduce friction almost completely. They are expensive to operate and require back-up bearings in case of failure.

(d) Near-frictionless carbon allows for very low coefficients of friction and very hard wear surfaces. Initial applications for this material include the space program and aircraft design.

45. First calculate the total mass of the books:
$m_T = 6.5\text{ kg} + 6.5\text{ kg} = 13\text{ kg}$
Consider all forces acting on the bottom book. Let F_{ft} represent the friction force exerted by the table surface and F_{fb} represent the friction force exerted by the book at the top. Since the book is not moving, $F_{net} = 0$.

$$\begin{aligned}
F_{net} &= F_{ft} - F_{fb} \\
0 &= F_{ft} - F_{fb} \\
F_{ft} &= F_{fb} \\
\mu_{St} m_T g &= \mu_{Sb} m_b g \\
\mu_{St} m_T &= \mu_{Sb} m_b \\
\mu_{Sb} &= \frac{\mu_{St} m_T}{m_b} \\
&= \frac{(0.15)(13\text{ kg})}{6.5\text{ kg}} \\
\mu_{Sb} &= 0.30
\end{aligned}$$

The minimum coefficient of static friction between the books is 0.30.

Analysis and Application

46. (a) When a person is riding an elevator, the acceleration of the elevator combines with the acceleration of gravity to make the person feel a net force that is different than the net force caused by gravity alone. When the elevator is accelerating upward, the acceleration brings the person closer to the floor. This acceleration combines with the acceleration due to gravity to create an increased net force toward the floor so the person feels heavier. When the elevator is accelerating downward, the acceleration brings the person farther away from the floor. This acceleration combines with the acceleration due to gravity to create a decreased net force toward the floor so the person feels lighter.
(b) Answers may vary. Sample answer:
Riding a roller coaster or a vehicle quickly over hills increases and decreases a person's acceleration in similar ways to riding an elevator.
47. Answers may vary. Sample answer:
In the diagram, the cannonball falls back to Earth's surface due to the gravitational force directed towards the centre of Earth. Since it is falling under the influence of gravity only, it is said to be in free fall. As the velocity of the cannonball increases from (a), the trajectory of the cannonball curves away from Earth's surface and travels farther and farther before it returns to Earth. At (e), the cannonball is fired with the right velocity to travel around Earth under the influence of Earth's gravitational field, but never returning to Earth. At (f), the cannonball can travel fast enough to escape from Earth's gravitational field. So trajectory (f) is the fastest.
48. Answers may vary. Sample answer:
From the photograph, the metal surface is not really levelled and there are grooves, cracks, and holes that will exert friction force on another surface that is in contact with it. It seems that no matter how smooth a surface appears to be, it is not perfectly smooth. That is why the coefficients of friction for materials are never zero.
49. (a) Use the equations $F_f = F_K = \mu_K F_N$ and $F_{net} = ma$ to determine the mass.

$$\begin{aligned}
F_{net} &= F_a - F_f \\
ma &= F_a - \mu_K F_N \\
ma &= F_a - \mu_K mg \\
ma + \mu_K mg &= F_a \\
m(a + \mu_K g) &= F_a \\
m &= \frac{F_a}{a + \mu_K g} \\
&= \frac{150\text{ N}}{2.53\text{ m/s}^2 + (0.15)(9.8\text{ m/s}^2)} \\
&= 37.5\text{ kg} \\
m &= 38\text{ kg}
\end{aligned}$$

The mass of the block is 38 kg.
(b) Since the block moves with a constant velocity, $F_{net} = 0$. Use the equation $F_f = F_K = \mu_K F_N$ to determine μ_K.

$$\begin{aligned}
0 &= F_a - F_f \\
F_f &= F_a \\
\mu_K F_N &= F_a \\
\mu_K mg &= F_a \\
\mu_K &= \frac{F_a}{mg} \\
&= \frac{150\text{ N}}{(37.5\text{ kg})(9.8\text{ m/s}^2)} \\
\mu_K &= 0.41
\end{aligned}$$

The coefficient of kinetic friction between the block and the new surface is 0.41.
50. (a) Use the equations $F_f = \mu_K F_N$ and $F_{net} = ma$ to determine the acceleration of each team.

Team 1:

$$F_{net} = F_1 - F_f$$
$$m_1a_1 = F_1 - \mu_K F_N$$
$$m_1a_1 = F_1 - \mu_K m_1 g$$
$$a_1 = \frac{F_1 - \mu_K m_1 g}{m_1}$$
$$= \frac{230\text{ N} - (0.01)(170\text{ kg})(9.8\text{ m/s}^2)}{170\text{ kg}}$$
$$a_1 = 1.25\text{ m/s}^2$$

Team 2:

$$F_{net} = F_2 - F_f$$
$$m_2a_2 = F_2 - \mu_K F_N$$
$$m_2a_2 = F_2 - \mu_K m_2 g$$
$$a_2 = \frac{F_2 - \mu_K m_2 g}{m_2}$$
$$= \frac{250\text{ N} - (0.01)(195\text{ kg})(9.8\text{ m/s}^2)}{195\text{ kg}}$$
$$a_2 = 1.18\text{ m/s}^2$$

The acceleration of team 1 is faster so team 1 will have a quicker start.

(b) For each team, the applied force is the same as the force of static friction and the acceleration is calculated as follows.

$$F_{net} = F_a - F_f$$
$$ma = \mu_S F_N - \mu_K F_N$$
$$ma = \mu_S mg - \mu_K mg$$
$$a = (\mu_S - \mu_K)g$$

The accelerations are independent of the mass of the sleds so both sleds have the same acceleration.

51. (a) Since there is no applied force, $F_{net} = F_{S_{max}}$.

$$F_{net} = F_{S_{max}}$$
$$ma = \mu_S F_N$$
$$ma = \mu_S mg$$
$$a = \mu_S g$$
$$= (0.05)(9.8\text{ m/s}^2)$$
$$a = 0.49\text{ m/s}^2$$

The broomball player is expected to create a maximum acceleration of 0.5 m/s^2.

(b) For a different value of μ_S,

$$F_{net} = F_{S_{max}}$$
$$ma = \mu_S F_N$$
$$ma = \mu_S mg$$
$$a = \mu_S g$$
$$= (0.85)(9.8\text{ m/s}^2)$$
$$a = 8.3\text{ m/s}^2$$

The maximum possible acceleration is 8.3 m/s^2.

(c) If a player of greater mass were on the same surface, the values above would not change.

52. Tread pattern could play a role in preventing hydroplaning. An example could be a tread pattern that sheds water away from the tire instead of requiring it to channel through the entire tread pattern.

53. If friction were reduced on all axes of an ice skate, the skater would never be able to use friction to increase her speed while skating or be able to turn.

Evaluation

54. Answers may vary. Sample answers:

(a) Advantages of creating an infrastructure in a lower gravitational field may include lower costs of building materials, transportation, and maintenance. Infrastructure would weigh less and therefore could be made smaller as it does not have to carry as much of it own weight. Transportation of a lighter and smaller structure would be easier. Friction wear on many components would be less and so repair and replacement costs would be lower. Disadvantages may include decreased stopping capabilities of vehicles and material manipulation via gravity. For example, extruding metal sheets through rollers would be more difficult.

(b) In a lower gravitational field, the human body would benefit from less joint wear. However, there could be some possible disadvantages. With lower gravitational field strength, the cells of the bones and muscles may adjust themselves so that the bones are no longer as strong as they are in Earth's gravitational field. Problems such as low bone density would occur.

(c) The obvious effect is that sports would have to be completely retooled. Regular-sized baseballs would be hit for home-runs each time players went for the ball. Basketball players would be able to jump to the rim without much skill or effort.

55. (a) If the Moon were closer to Earth, tidal shifts would be greater because the pull by the Moon's gravitational field increases as the distance from the Moon's surface decreases.
(b) If the Moon had less gravitational pull, the magnitude of the tidal shifts would be smaller.
(c) Answers may vary. Sample answer:
One possible effect of having multiple moons would be multiple tidal shifts of varying magnitude based on the gravitational field strength and the distance of each of the moons.
56. Answers may vary. Sample answer:
To determine the coefficients of friction, the experimental procedure should include measuring the normal force, the applied force, and the acceleration of an object on a surface very accurately. Surface conditions such as humidity, wetness, dust, or dirt would affect results. These variables could be catalogued with their associated friction coefficients so as to characterize a more complete description of the friction interaction of the materials.
57. Answers may vary. Sample answer:
Without friction, driving as we know it would not be possible. Car tires would not be able to push against the road, leaving the car in place. Other propulsion methods would have to be substituted for the friction between tires and road. Perhaps rockets could be used for automobile propulsion.
58. Answers may vary. Sample answers:
(a) Friction loss has an impact on the fuel efficiency of the engine of a car. Some energy coming from the fuel is wasted in the form of heat due to friction. As a result the fuel efficiency of the car decreases.
(b) Friction could be minimized by decreasing the number of moving parts or by adding bearings and lubricants between sliding parts to reduce friction.
59. Answers may vary. Sample answers:
(a) Table 1 shows that there are challenges with predicting forces between two parts of greasy steel because the coefficients of friction are shown as ranges. To predict a force accurately, the coefficient of friction must be known exactly. A range of coefficients will create a range of possible forces.
(b) Engineers might overcome the uncertainty by using in their designs materials that have more certain coefficients of friction.
(c) Many variables go into the forces experienced by a golf club. These include the speed of the club, the swing angle at which the club hits the ball, the face angle at which the ball hits the club, and the location of impact.

Reflect on Your Learning

60. Answers may vary. Sample answer:
(a) Car tires take advantage of gravity-induced friction to move cars and allow people to travel much longer distances than they otherwise would be able to.
(b) The soles of boots are manufactured with rubber that has a high coefficient of kinetic friction to increase the grip as we walk on icy or slippery surfaces.
61. (a) Mass and weight can be used interchangeably because there is a direct correlation between mass and weight if the gravitational field is consistent, which it is on Earth's surface.
(b) In the context of physics, the assumption cannot be made that a specific mass corresponds to a specific weight. This assumption is wrong when the gravitational force changes. Further, the mass is related to the net force by the mass's acceleration. This means that mathematically, mass and force are different. Since weight is the product of mass and gravitational acceleration, weight is a force.
62. Answers may vary. The first part of the answer may be as follows: Air resistance can be used to our advantage as a transportation mode in sailing. Sailboats use air resistance as their primary propulsion force. Many other vehicles, such as planes and cars have to use large quantities of energy to overcome the forces that air resistance applies in the direction opposite to the vehicle's motion. The second part of the answer should include a discussion about students' introduction to air resistance before reading this chapter. It could be some real world scenarios such as riding a bike into the wind or a classroom oriented introduction.
63. Answers may vary. The safety features known before reading this chapter may include seat belts and airbags, and others discussed in this chapter. Safety features seen advertised (which is popular among auto makers) or outside of this chapter may also be included. A thoughtful answer should indicate that these safety features do not make cars completely safe or accident resistant so drivers should always drive with utmost caution.

Research

64. Answers may vary. Students' answers should state the mathematical formula for the gravitational force between two objects and describe the variables involved in the equation. The force should be explained in words in accompaniment to the equation.

65. Answers may vary. Students' answers should demonstrate a thorough understanding of regenerative braking and how it relates to energy conservation.

66. Answers may vary. Students' answers should include events such as Leonardo da Vinci's initial concept, the first soft parachute created, the first manned parachute, parachute uses in pre-airplane context, and other historical developments.

67. Answers may vary. Students' answers should include other scientific contributions, such as Amontons' hygrometer improvement and his work with an implication of absolute zero.

68. Answers may vary. Students' answers should include, along with his standard biographical information, a discussion of Coulomb's contributions to electricity regarding the relationship between force and distance of electric currents.

69. Answers may vary. Students' answers should describe how matches work (with a special focus on friction) and include a history of matches.

Chapter 4 Self-Quiz, page 197

1. (b)
2. (d)
3. (b)
4. (d)
5. (a)
6. (d)
7. (a)
8. (c)
9. False. Free fall is when *only gravity is* acting on a falling object.
10. True
11. False. When an object is sliding, it experiences a *smaller* magnitude of friction force than when it is stationary.
12. False. *Static* friction is the force exerted on an object by a surface that prevents a stationary object from moving.
13. True
14. False. If the force produced by a train engine is not large enough to overcome the combined static friction of the cars, it will move *none* of the cars.
15. True
16. False. Electricity stability control uses *both* traction control *and* an antilock braking system.
17. False. When airbags are deployed, the driver of the vehicle *may* become injured.
18. False. Magnetic bearing systems *do require* back-up bearings because they *can* fail.
19. True
20. False. Near-frictionless carbon has a coefficient of friction *less* than that of Teflon.

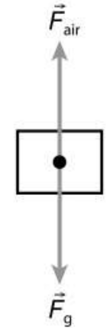
Unit 2 Review, pages 208–215

Knowledge

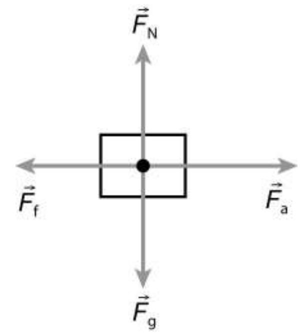
1. (b)
2. (a)
3. (a)
4. (b)
5. (a)
6. (a)
7. (b)
8. (d)
9. (c)
10. (a)
11. (c)
12. (a)
13. (a)
14. False. Friction is a force that acts to *resist the motion or attempted motion* of an object.
15. False. In the nucleus of atoms, the *strong nuclear force* holds together the protons and neutrons.
16. False. Gravity is the only fundamental force that does not have a *repulsive* effect.
17. True
18. False. A force of 10 N that acts on a box with a mass of 2.5 kg will accelerate it at a rate of 4 m/s^2 *as long as there are no other forces* acting on the box.
19. False. Steven Hawking considers *Newton* to be the greatest figure in mathematical physics and the *Principia* is his greatest work.
20. True
21. False. On the Moon, *only* your weight will decrease.
22. False. For a flat surface, the static frictional force can be determined by multiplying the coefficient of static friction by the *normal force* of an object.
23. True
24. True
25. (a) (iv)
(b) (ii)
(c) (vi)
(d) (v)
(e) (i)
(f) (iii)
26. From least amount of inertia to most amount of inertia: proton, atom, pencil, baseball, hockey player, motorcycle, car
27. From least amount of kinetic friction to most amount of kinetic friction: ice on ice, Teflon on Teflon, wood on dry snow, rubber on concrete

Understanding

28. (a)

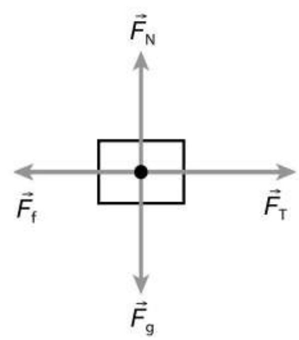


(b)

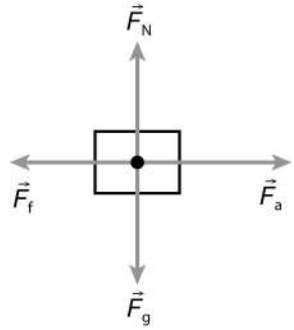


29. Answers may vary. Sample answer:
A system diagram is a simple sketch of the objects involved in the problem and is used to show how each object is interacting with others. A free-body diagram is a basic vector diagram that shows all of the forces acting on a single object. It is used to determine the net force acting on an object and to help set up force equations.

30. (a)



(b)



(c) Answers may vary. Sample answer: There are no differences between the FBDs in parts (a) and (b). The direction of each arrow depends on the direction you choose to start drawing a FBD. If you choose right for the direction of the pulling force in (a) and you choose right for the direction of the pushing force in (b), you will end up with the same force diagram for the two different situations.

31. Choose force northward as positive. So force southward is negative.

$F_{net} = +42\ 000\text{ N} + (-1200\text{ N})$

$F_{net} = +40\ 800\text{ N}$

The net horizontal force on the plane is 40 800 N [northward].

32. According to Newton's first law, when an object is at rest, the net force on the object must be zero. So the normal force pushing upward on the book must be equal to the force of gravity pulling downward for the book to remain at rest.

33. Answers may vary. Sample answer: The ball is in a horizontal motion when it is in the ballistic cart. Since there are no horizontal forces acting on the ball, it continues this horizontal motion following Newton's first law. When the ball is fired upward, it rises and falls due to the shooting force and the force of gravity in the vertical direction, but at the same time continues to move horizontally. As a result, the ball follows an arched path.

34. Choose right as positive. So left is negative. Since the rope does not break and the students are stationary, $F_{net} = 0$.

$\vec{F}_{net} = \vec{F}_{R1} + \vec{F}_{R2} + \vec{F}_{L1} + \vec{F}_{L2}$

$0 = +95\text{ N} + 87\text{ N} + (-104\text{ N}) + F_{L2}$

$F_{L2} = -78\text{ N}$

$\vec{F}_{L2} = 78\text{ N [left]}$

The fourth student on the left is pulling with a force of 78 N [left].

35. (a) According to Newton's second law, an object will accelerate in the direction of the net force with a magnitude given by $a = \frac{F_{net}}{m}$. If two cars are pushed by an equivalent net force, the one that has less mass will accelerate faster.

(b) As more boxes are added to the cart, the mass of the cart will increase. If the person continues to pull with a constant force, the acceleration of the cart will decrease.

36. (a) Given: $m = 68$ kg; $\vec{a} = 2.4\text{ m/s}^2$ [forwards]

Required: $\vec{F}_{net}$

Analysis: Use the equation $F_{net} = ma$ to calculate F_{net}. Choose forwards as positive. So backwards is negative.

Solution:

$F_{net} = ma$

$= (68\text{ kg})(+2.4\text{ m/s}^2)$

$F_{net} = +160\text{ N}$

Statement: The net force acting on the sprinter is 160 N [forwards].

(b) Given: $m = 0.425$ kg; $\vec{a} = 9.8\text{ m/s}^2$ [down]

Required: $\vec{F}_{net}$

Analysis: Use the equation $F_{net} = ma$ to calculate F_{net}. Choose up as positive. So down is negative.

Solution:

$F_{net} = ma$

$= (0.425\text{ kg})(-9.8\text{ m/s}^2)$

$F_{net} = -4.2\text{ N}$

Statement: The net force acting on the baseball is 4.2 N [down].

37. (a) Given: $m = 2200$ kg; $\vec{F}_{net} = 4500$ N [N]

Required: $\vec{a}$

Analysis: Use the equation $a = \frac{F_{net}}{m}$ to calculate a. Choose north as positive. So south is negative.

Solution:

$a = \frac{F_{net}}{m}$

$= \frac{+4500\text{ N}}{2200\text{ kg}}$

$a = +2.0\text{ m/s}^2$

$\vec{a} = 2.0\text{ m/s}^2$ [N]

Statement: The acceleration of the car is 2.0 m/s^2 [N].

(b) Given: m = 71.2 kg; F_{net} = 245 N [up]
Required: a

Analysis: Use the equation $a = \frac{F_{net}}{m}$ to calculate a.

Choose up as positive. So down is negative.
Solution:

$$\begin{aligned} a &= \frac{F_{net}}{m} \\ &= \frac{+245 \text{ N}}{71.2 \text{ kg}} \\ a &= +3.44 \text{ m/s}^2 \\ \vec{a} &= 3.44 \text{ m/s}^2 [\text{up}] \end{aligned}$$

Statement: The acceleration of the skydiver is 3.44 m/s^2 [up].

38. Given: m = 0.175 kg; a = 1.3 m/s^2
Required: $\vec{F}_{net}$
Analysis: The frictional force is the net force acting on the puck. Use the equation $F_{net} = ma$ to calculate F_{net}. Choose forwards as positive. So backwards is negative. Since the puck is slowing down, the acceleration should be negative (backwards).
Solution:

$$\begin{aligned} F_{net} &= ma \\ &= (0.175 \text{ kg})(-1.3 \text{ m/s}^2) \\ F_{net} &= -0.23 \text{ N} \end{aligned}$$

Statement: The frictional force acting on the puck is 0.23 N [backwards].

39. Given: m = 0.145 kg; $\vec{F}_{net} = 8.0 \times 10^3$ N [S]
Required: $\vec{a}$

Analysis: Use the equation $a = \frac{F_{net}}{m}$ to calculate a.

Choose north as positive. So south is negative.
Solution:

$$\begin{aligned} a &= \frac{F_{net}}{m} \\ &= \frac{-8.0 \times 10^3 \text{ N}}{0.145 \text{ kg}} \\ a &= -5.5 \times 10^4 \text{ m/s}^2 \\ \vec{a} &= 5.5 \times 10^4 \text{ m/s}^2 \text{ [S]} \end{aligned}$$

Statement: The acceleration of the ball is 5.5×10^4 m/s^2 [S].

40. Choose right as positive. So left is negative.
(a) For the cart,

$$\begin{aligned} F_{net} &= F_T \\ m_1 a &= F_T \quad \text{(Equation 1)} \end{aligned}$$

For the hanging object,

$$\begin{aligned} F_{net} &= F_g - F_T \\ m_2 a &= m_2 g - F_T \quad \text{(Equation 2)} \end{aligned}$$

Add the equations to solve for a.

$$\begin{aligned} m_1 a + m_2 a &= F_T + m_2 g - F_T \\ (m_1 + m_2)a &= m_2 g \\ a &= \frac{m_2 g}{m_1 + m_2} \\ &= \frac{(0.20 \text{ kg})(+9.8 \text{ m/s}^2)}{0.4 \text{ kg} + 0.20 \text{ kg}} \\ a &= +3.3 \text{ m/s}^2 \end{aligned}$$

The acceleration of the cart is 3.3 m/s^2 [right].

(b) For the cart, $F_{net} = F_T - F_f$

$$m_1 a = F_T - F_f \quad \text{(equation 1)}$$

For the hanging object, $F_{net} = F_g - F_T$

$$m_2 a = m_2 g - F_T \quad \text{(equation 2)}$$

Add the equations to solve for a.

$$\begin{aligned} m_1 a + m_2 a &= F_T - F_f + m_2 g - F_T \\ (m_1 + m_2)a &= m_2 g - F_f \\ a &= \frac{m_2 g - F_f}{m_1 + m_2} \\ &= \frac{(0.20 \text{ kg})(+9.8 \text{ m/s}^2) - 0.10 \text{ N}}{0.4 \text{ kg} + 0.20 \text{ kg}} \\ a &= 3.1 \text{ m/s}^2 \end{aligned}$$

The acceleration of the cart is 3.1 m/s^2 [right].

(c) Use equation 2 in part (b).

$$\begin{aligned} m_2 a &= m_2 g - F_T \\ F_T &= m_2 g - m_2 a \\ &= m_2 (g - a) \\ &= (0.20 \text{ kg})(9.8 \text{ m/s}^2 - 3.1 \text{ m/s}^2) \\ F_T &= 1.3 \text{ N} \end{aligned}$$

The magnitude of the tension in the string is 1.3 N.

41. (a) The force of the student pushing on the skateboard causes it to accelerate in that direction. According to Newton's third law, the skateboard exerts a reaction force of equal magnitude pushing back on the student, causing him to accelerate away from the skateboard.
(b) When the person leans against the wall with a certain amount of force, the wall exerts a reaction force of equal magnitude but in opposite direction on the person. The net force acting on the person is zero and the wall is anchored to the ground so they both remain stationary.

(c) As the ball rolls forwards and hits the group of balls with a force, the group of balls exerts a reaction force of equal magnitude but in opposite direction on the ball, causing it to roll backwards.

42. (a) Given: m = 80 kg; F_a = 68 N; F_f = 30 N

Required: $\vec{a}$

Analysis: Choose forwards as positive. So backwards is negative. Use the equation $F_{net} = F_a + F_f$ to find a.

Solution:

$$F_{net} = F_a + F_f$$
$$ma = F_a + F_f$$
$$(80 \text{ kg})a = 68 \text{ N} + (-30 \text{ N})$$
$$a = \frac{38 \text{ N}}{80 \text{ kg}}$$
$$a = 0.48 \text{ m/s}^2$$
$$\vec{a} = 0.48 \text{ m/s}^2 \text{ [forward]}$$

Statement: The acceleration of the player is 0.48 m/s^2 [forwards], off the boards.

(b) The boards do not move because they are massive and anchored to the ground. Since $a = \frac{F_{net}}{m}$, for a large value of m, the value a will be very small. The force that the player pushes with is so small compared to the mass of the boards that their acceleration is not noticeable.

43. (a) Given: F_{net} = 0 N; m = 0.50 kg, g = –9.8 m/s^2

Required: F_T

Analysis: . The forces on the weight are the tension pulling it upward and the gravity pulling it downward. Add all the vertical forces: $F_{net} = F_T + F_g$. Choose up as positive. So down is negative. Since the helicopter is stationary, F_{net} = 0.

Solution:

$$F_{net} = F_T + F_g$$
$$0 = F_T + mg$$
$$F_T = -mg$$
$$= -(0.50 \text{ kg})(-9.8 \text{ m/s}^2)$$
$$F_T = +4.9 \text{ N}$$

Statement: The tension in the string is 4.9 N.

(b) Given: m = 0.50 kg; g = –9.8 m/s^2; a = +0.80 m/s^2

Required: F_T

Analysis: In this situation, $F_{net} = ma$. Choose up as positive. So down is negative.

Solution:

$$F_{net} = F_T + F_g$$
$$ma = F_T + mg$$
$$F_T = ma - mg$$
$$= (0.50 \text{ kg})(+0.80 \text{ m/s}^2) - (0.50 \text{ kg})(-9.8 \text{ m/s}^2)$$
$$F_T = +5.3 \text{ N}$$

Statement: The tension in the string is 5.3 N.

(c) Given: m = 0.50 kg; g = –9.8 m/s^2; a = –0.92 m/s^2

Required: F_T

Analysis: In this situation, $F_{net} = ma$. Choose up as positive. So down is negative.

Solution:

$$F_{net} = F_T + F_g$$
$$ma = F_T + mg$$
$$F_T = ma - mg$$
$$= (0.50 \text{ kg})(-0.92 \text{ m/s}^2) - (0.50 \text{ kg})(-9.8 \text{ m/s}^2)$$
$$F_T = +4.4 \text{ N}$$

Statement: The tension in the string is 4.4 N.

44. (a) The force of gravity and air resistance are the forces acting on the brick as it falls.

(b) In the instant the brick is initially dropped, the force of gravity acts more strongly.

(c) As the brick reaches its terminal speed, the force of gravity and air resistance are equal in magnitude and acting in opposite directions.

(d) Given: m = 0.22 kg; g = –9.8 m/s^2

Required: F_{air}

Analysis: Since the net force on the brick is zero, at terminal speed, $F_{air} = F_g$.

Solution:

$$F_{air} = F_g$$
$$= mg$$
$$= (0.22 \text{ kg})(9.8 \text{ m/s}^2)$$
$$F_{air} = 2.2 \text{ N}$$

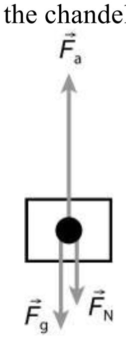
Statement: The force of air resistance is 2.2 N.

45. (a) Answers may vary. Sample answer:
One way to measure gravitational field strength is to measure the weight of a known mass and divide the weight by the mass. A second way is to measure the acceleration of an object falling from a known height.

(b) Use the equation $F_g = mg$ to determine g.

$$F_g = mg$$
$$g = \frac{F_g}{m} = \frac{24.475\ \text{N}}{2.50\ \text{kg}}$$
$$g = 9.79\ \text{N/kg}$$

The gravitational field strength acting on the object is 9.79 N/kg.
(c) This altitude is probably above sea level because the gravitational field strength is lower than that at sea level.
46. (a) Mass is the quantity of matter in an object. Weight is a measure of the force of gravity acting on an object.
(b) It is possible to change the mass of an object by adding or removing material from that object.
(c) To change the weight of an object, but not the mass, move the object to a location with a different gravitational field strength.
(d) The magnitudes of an object's mass and weight will be equal when the gravitational field strength equals 1 N/kg.
47. (a) If both cylinders hit the ground at the same time, the cylinder with the greater mass has a larger cross-sectional area.
(b) If they have the same cross-sectional area, the cylinder with the greater mass will hit the ground first.
(c) If both cylinders were dropped in a vacuum, there is no air resistance and they would hit the ground at the same time.
48. Draw a FBD of the chandelier.

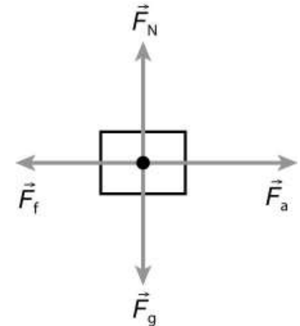


The chandelier is at rest. So the net force on the chandelier is zero.
Choose up as positive. So down is negative.

$$F_N + F_g + F_a = 0$$
$$F_N + (3.2\ \text{kg})(-9.8\ \text{m/s}^2) + 53\ \text{N} = 0$$
$$F_N = -22\ \text{N}$$

The normal force acting on the chandelier is 22 N [down].

49. (a) The forces acting on the rock are the force of gravity, the normal force, the applied force, and static friction.
(b)



(c) Given: m = 210 kg; g = –9.8 m/s^2
Required: $\vec{F}_N$
Analysis: Consider the vertical forces acting on the rock. Choose up as positive. So down is negative.
Solution: Since the net force on the rock is zero,

$$F_N + F_g = 0$$
$$F_N = -F_g = -mg = -(210\ \text{kg})(-9.8\ \text{m/s}^2)$$
$$F_N = +2100\ \text{N}$$

Statement: The normal force acting on the rock is 2100 N [up].
50. (a) Given: m = 5.0 kg; $F_{S_{max}}$ = 29.89 N
Required: μ_S
Analysis: Use the equation $\mu_S = \frac{F_{S_{max}}}{F_N}$ to find μ_S.
Solution:

$$\mu_S = \frac{F_{S_{max}}}{F_N} = \frac{F_{S_{max}}}{mg} = \frac{28.89\ \text{N}}{(5.0\ \text{kg})(9.8\ \text{m/s}^2)}$$
$$\mu_S = 0.61$$

Statement: The coefficient of static friction is 0.61.
(b) The two materials involved in this interaction are leather and oak.
51. (a) Given: F_N = 52 N; μ_S = 0.1
Required: $F_{S_{max}}$
Analysis: The initial force required is the maximum static friction. Use the equation $F_{S_{max}} = \mu_S F_N$ to calculate $F_{S_{max}}$.

Solution:

$F_{S_{max}} = \mu_S F_N$

$= (0.1)(52\ \text{N})$

$F_{S_{max}} = 5.2\ \text{N}$

Statement: The magnitude of the initial horizontal force required is 5.2 N.

(b) Given: F_N = 52 N; μ_K = 0.03

Required: F_K

Analysis: The force required is the kinetic friction. Use the equation $F_K = \mu_K F_N$ to calculate F_K.

Solution:

$F_K = \mu_K F_N$

$= (0.03)(52\ \text{N})$

$F_K = 1.6\ \text{N}$

Statement: The force required to maintain the hut sliding at a constant speed is 1.6 N.

52. (a) Given: m = 12 kg; $F_{S_{max}}$ = 47 N

Required: μ_S

Analysis: Use the equation $\mu_S = \dfrac{F_{S_{max}}}{F_N}$ to find μ_S.

Solution:

$$\mu_S = \frac{F_{S_{max}}}{F_N}$$

$$= \frac{F_{S_{max}}}{mg}$$

$$= \frac{47\ \text{N}}{(12\ \text{kg})(9.8\ \text{m/s}^2)}$$

$\mu_S = 0.40$

Statement: The coefficient of static friction is 0.40.

(b) Given: m = 12 kg; F_a = 47 N; a = 1.1 m/s^2

Required: μ_K

Analysis: Use the equations $F_{net} = F_K + F_a$ and $F_K = \mu_K F_N$ to find μ_K. Choose forwards as positive. So backwards is negative.

Solution:

$F_{net} = F_K + F_a$

$ma = -\mu_K F_N + 47\ \text{N}$

$ma = -\mu_K mg + 47\ \text{N}$

$(12\ \text{kg})(1.1\ \text{m/s}^2) = -\mu_K (12\ \text{kg})(9.8\ \text{m/s}^2) + 47\ \text{N}$

$\mu_K = 0.29$

Statement: The coefficient of kinetic friction is 0.29.

53. Given: m = 72 kg; μ_S = 0.79

Required: $\vec{a}$

Analysis: At the time the runner starts from rest, $F_{net} = F_{S_{max}}$. Use the equations $F_{S_{max}} = \mu_S F_N$ $F_{net} = ma$ to find a. Choose forwards as positive. So backwards is negative.

Solution:

$F_{S_{max}} = \mu_S F_N$

$F_{net} = \mu_S mg$

$ma = \mu_S mg$

$a = \mu_S g$

$= (0.79)(9.8\ \text{m/s}^2)$

$a = 7.7\ \text{m/s}^2$

$\vec{a} = 7.7\ \text{m/s}^2$ [forward]

Statement: The maximum acceleration of the runner is 7.7 m/s^2 [forwards].

54. Given: m = 6.2 kg; a = 0.50 m/s^2; μ_K = 0.24

Required: F_a

Analysis: Use the equations $F_{net} = F_K + F_a$ and $F_K = \mu_K F_N$ to find F_a.

Solution: Choose forwards as positive. So backwards is negative.

$F_{net} = F_K + F_a$

$ma = -\mu_K F_N + F_a$

$F_a = ma + \mu_K F_N$

$= ma + \mu_K mg$

$= m(a + \mu_K g)$

$= (6.2\ \text{kg})[0.50\ \text{m/s}^2 + (0.24)(9.8\ \text{m/s}^2)]$

$F_a = 18\ \text{N}$

Statement: The magnitude of the force that the man pulls is 18 N.

55. Given: m = 22 kg; v_i = 5.2 m/s; μ_K = 0.44

Required: Δd

Analysis: First use the equations $F_{net} = F_K$ and $F_K = \mu_K F_N$ to find the acceleration of the box. Then use the equation $v_f^2 = v_i^2 + 2a\Delta d$ to calculate the distance travelled. Since the box comes to rest, v_f = 0 m/s.

Solution:

$F_{net} = F_K$

$ma = \mu_K F_N$

$ma = \mu_K mg$

$a = \mu_K g$

$= (0.44)(9.8\ \text{m/s}^2)]$

$a = 4.31\ \text{m/s}^2$ (one extra digit carried)

Now calculate the distance travelled. Choose forwards as positive. So backwards is negative.

$$v_f^2 = v_i^2 + 2a\Delta d$$
$$0 = v_i^2 + 2a\Delta d$$
$$v_i^2 = -2a\Delta d$$
$$\Delta d = \frac{v_i^2}{-2a}$$
$$= \frac{(+5.2 \text{ m/s})^2}{-2(-4.31 \text{ m/s}^2)}$$
$$\Delta d = 3.1 \text{ m}$$

Statement: The box slides 3.1 m before it comes to rest.

56. Answers may vary. Sample answers:
(a) One safety feature is the seat belt. A seat belt is designed to keep a person in an optimal crash position in a car seat to prevent the person from accelerating toward the dashboard or windshield during a car accident. Another safety feature is the crumple zone. The crumple zones of a car are designed to crush during an accident. The crushing action increases the time it takes to stop the car during a collision, reducing both the acceleration and the forces acting on the people inside the car.
(b) During a crash test, an engineer uses a dummy to accurately simulate what will happen to a person during a car accident. The information gathered includes the accelerations of different parts of the body (like the head and torso) using accelerometers, how much the chest gets compressed during the crash using a motion sensor, and other forces acting on the body using load sensors all over the body.
(c) In the photograph, the crumple zone in the front of the car is crushed while the car test dummy stays inside in the car seat uninjured.

57. Answers may vary. Sample answer:
When a person sits, the hip has to support the upper body's weight and the hip slides quite often on different seat surfaces. So the material used in hip replacement must be strong, flexible but sturdy, wear resistant, and durable for the artificial hip to look good in its shape, function properly, and last longer.

58. Answers may vary. Students' answers should explain their findings about snow tires. Sample student answer: The tread pattern on snow tires is specifically designed to dig into the snow and create more friction. They are also made from a softer rubber that allows the tires to flex in the winter and grip the road. Snow tires cannot be left on all year because the soft rubber will wear a lot more easily during the summer and ruin their traction for the winter.

Analysis and Application

59. (a) The ball should go up to a height of 25 cm because of inertia. The amount of inertia the ball carries down the first ramp is the same as that it will carry up the second ramp.
(b) After rolling back, the ball should once again roll up to a height of 25 cm.
(c) This cannot happen in real world because of friction. It causes the ball to slow down and lose inertia.

60. Given: $v_2 = 32$ m/s; $\Delta t = 0.42$ s; $m = 0.22$ kg
Required: F_{net}
Analysis: First use the equation $v_2 = v_1 + a\Delta t$ to calculate the acceleration. Then use $F_{net} = ma$ to calculate the average force on the potatoes.
Solution: At the beginning, the velocity of the potatoes is 0 m/s.

$$v_2 = v_1 + a\Delta t$$
$$v_2 = a\Delta t$$
$$a = \frac{v_2}{\Delta t}$$
$$= \frac{32 \text{ m/s}}{0.42 \text{ s}}$$
$$a = 76.2 \text{ m/s}^2 \text{ (one extra digit carried)}$$

Now calculate the average force.

$$F_{net} = ma$$
$$= (0.22 \text{ kg})(76.2 \text{ m/s}^2)$$
$$F_{net} = 17 \text{ N}$$

Statement: The average force the potato gun exerts on the potatoes is 17 N.

61. Given: $m = 71$ kg; $v_1 = 3.4$ m/s; $v_2 = 6.7$ m/s; $\Delta t = 2.8$ s
Required: F_{net}
Analysis: First use the equation $v_2 = v_1 + a\Delta t$ to calculate the acceleration. Then use $F_{net} = ma$ to calculate the net force on the runner.
Solution:

$$v_2 = v_1 + a\Delta t$$
$$a = \frac{v_2 - v_1}{\Delta t}$$
$$= \frac{6.7 \text{ m/s} - 3.4 \text{ m/s}}{2.8 \text{ s}}$$
$$a = 1.18 \text{ m/s}^2 \text{ (one extra digit carried)}$$

Now calculate the average force.

$$F_{net} = ma$$
$$= (71 \text{ kg})(1.18 \text{ m/s}^2)$$
$$F_{net} = 84 \text{ N}$$

Statement: The net force the runner experiences is 84 N.

62. (a) Given: $m_T = 9.0 \text{ kg} + 3.0 \text{ kg} = 12.0 \text{ kg}$; $F_f = 18 \text{ N} + 6.0 \text{ N} = 24 \text{ N}$; $F_a = 30.0 \text{ N}$

Required: $\vec{a}$

Analysis: We can treat the two weights as one single object. Use the equations $F_{net} = F_a + F_f$ and $F_{net} = ma$ to calculate the acceleration. Choose forwards as positive. So backwards is negative.

Solution:

$$F_{net} = F_a + F_f$$
$$ma = F_a + F_f$$
$$(12.0 \text{ kg})a = 30.0 \text{ N} + (-24 \text{ N})$$
$$a = 0.50 \text{ m/s}^2$$
$$\vec{a} = 0.50 \text{ m/s}^2 \text{ [forward]}$$

Statement: The acceleration of the weights during the first 5.0 s is 0.50 m/s^2 [forwards].

(b) If the applied force is removed, the only horizontal force acting on the weights is friction, which is in the opposite direction of their motion. So the weight will slow down and stop.

(c) Answers may vary. Sample answer:
The two weights will move the same distance because the only force acting on the weights after the initial push is the frictional force, which is proportional to the normal force.

$$F_f = \mu_K F_N$$
$$ma = \mu_K mg$$
$$a = \mu_K g$$

The acceleration depends only on the coefficient of friction and the force of gravity, which are the same for both weights. Thus, both weights slow down at the same rate and travel the same distance.

63. Calculate the net force on the students and use $F_{net} = ma$ to calculate the acceleration. Choose right as positive. So left is negative.

$$F_{net} = F_{R1} + F_{R2} + F_{L1} + F_{L2}$$
$$= +55 \text{ N} + 65 \text{ N} + (-58 \text{ N}) + (-70 \text{ N})$$
$$F_{net} = -8 \text{ N}$$

The total mass of the students is:
$m_T = 60 \text{ kg} + 62 \text{ kg} + 59 \text{ kg} + 64 \text{ kg} = 245 \text{ kg}$

Now calculate the acceleration.

$$F_{net} = m_T a$$
$$-8 \text{ N} = (245 \text{ kg})a$$
$$a = \frac{-8 \text{ N}}{245 \text{ kg}}$$
$$a = -0.03 \text{ m/s}^2$$

The students accelerate to the left with a magnitude of 0.03 m/s^2.

64. (a) Given: $m = 220$ kg; $\Delta v = 5.0$ km/h; $\Delta t = 8.0$ s

Required: F_{dog}

Analysis: First use $a = \frac{\Delta v}{\Delta t}$ to calculate the acceleration. Then use $F_{net} = ma$ to find F_{dog}.

Solution: Convert the velocity to SI metric units.

$$5.0 \text{ km/h} = \left(5.0 \frac{\cancel{\text{km}}}{\cancel{\text{h}}}\right)\left(\frac{1 \cancel{\text{h}}}{60 \cancel{\text{min}}}\right)\left(\frac{1 \cancel{\text{min}}}{60 \text{ s}}\right)\left(\frac{1000 \text{ m}}{1 \cancel{\text{km}}}\right)$$
$$= 1.389 \text{ m/s (two extra digits carried)}$$

Then calculate the acceleration.

$$a = \frac{\Delta v}{\Delta t}$$
$$= \frac{1.389 \text{ m/s}}{8.0 \text{ s}}$$
$$a = 0.1736 \text{ m/s}^2 \text{ (two extra digits carried)}$$

Calculate the average applied force.

$$F_{net} = ma$$
$$= (220 \text{ kg})(0.1736 \text{ m/s}^2)$$
$$F_{net} = 38.19 \text{ N (two extra digits carried)}$$

For each dog,

$$F_{dog} = \frac{38.19 \text{ N}}{9}$$
$$F_{dog} = 4.2 \text{ N}$$

Statement: The average force applied by each dog is 4.2 N.

(b) The frictional force equals the total force applied by the dogs.

Given: $F_{dog} = 51$ N; $F_{net} = 38.19$ N

Required: F_f

Analysis: $F_{net} = F_a - F_f$

Solution:

$$F_a = 9 \times 51 \text{ N}$$
$$F_a = 459 \text{ N}$$

During the pulling motion,

$$F_{\text{net}} = F_{\text{a}} - F_{\text{f}}$$
$$38.19 \text{ N} = 459 \text{ N} - F_{\text{f}}$$
$$F_{\text{f}} = 420 \text{ N}$$

Statement: The frictional force acting on the sled is 420 N in a direction opposite to the motion.

65. (a) Calculate 38% of 9.8 m/s^2.

$$g_{\text{Mars}} = 0.38g$$
$$= 0.38(9.8 \text{ m/s}^2)$$
$$g_{\text{Mars}} = 3.72 \text{ m/s}^2 \text{ (one extra digit carried)}$$

The acceleration due to gravity on Mars is 3.7 m/s^2.

(b) Given: m = 180 kg; g_{Mars} = 3.72 m/s^2

Required: F_{gMars}

Analysis: Use $F_{\text{gMars}} = mg_{\text{Mars}}$ to calculate F_{gMars}.

Solution:

$$F_{\text{gMars}} = mg_{\text{Mars}}$$
$$= (180 \text{ kg})(3.72 \text{ m/s}^2)$$
$$F_{\text{gMars}} = 670 \text{ N}$$

Statement: The rover would weigh 670 N on Mars.

(c) Given: $g_{\text{Mars}} = 0.38g$; F_{g} = 8500 N

Required: F_{gMars}

Analysis: Use $F_{\text{gMars}} = mg_{\text{Mars}}$ to calculate F_{gMars}.

Solution:

$$F_{\text{gMars}} = mg_{\text{Mars}}$$
$$= m(0.38g)$$
$$= 0.38mg$$
$$= 0.38F_{\text{g}}$$
$$= 0.38(8500 \text{ N})$$
$$F_{\text{gMars}} = 3200 \text{ N}$$

Statement: The rock would experience a force of 3200 N on Mars.

66. (a) As the jumpers jumps off the boat, they exert an action force pushing the boat to the left. The boat exerts a reaction force of the same magnitude but to the opposite direction (to the right) on the jumpers.

(b) Given: F_{net} = 280 N; m_{j} = 130 kg; m_{b} = 220 kg

Required: $\vec{a}_{\text{j}}$; $\vec{a}_{\text{b}}$

Analysis: Use $F_{\text{net}} = ma$ to calculate the accelerations of the jumpers and the boat. Choose right as positive. So left is negative.

Solution:

For the jumpers:

$$F_{\text{net}} = m_{\text{j}}a_{\text{j}}$$
$$a_{\text{j}} = \frac{F_{\text{net}}}{m_{\text{j}}}$$
$$= \frac{+280 \text{ N}}{130 \text{ kg}}$$
$$a_{\text{j}} = +2.2 \text{ m/s}^2$$
$$\vec{a}_{\text{j}} = +2.2 \text{ m/s}^2 \text{ [right]}$$

For the boat, the net force is acting in the opposite direction.

$$F_{\text{net}} = m_{\text{b}}a_{\text{b}}$$
$$a_{\text{b}} = \frac{F_{\text{net}}}{m_{\text{b}}}$$
$$= \frac{-280 \text{ N}}{220 \text{ kg}}$$
$$a_{\text{b}} = -1.3 \text{ m/s}^2$$
$$\vec{a}_{\text{b}} = -1.3 \text{ m/s}^2 \text{ [left]}$$

Statement: The acceleration of the jumpers is 2.2 m/s^2 [right] and the acceleration of the boat is 1.3 m/s^2 [left].

67. Answers may vary. Sample answer:
As the heated and compressed air is expelled rapidly out of the rear of the engine, according to Newton's third law, the heated and expanded air exerts an equal but opposite force forwards to the back of the engine, causing the jet to accelerate.

68. (a) Given: m_1 = 2.0 kg; m_2 = 4.0 kg; m_{T} = 2.0 kg + 4.0 kg = 6.0 kg; F_{TA} = 12 N [forwards]

Required: $\vec{a}$; $\vec{F}_{\text{TB}}$

Analysis: Since there are no other forces acting on the masses, we can treat the two masses as a single object and use the equations $F_{\text{TA}} = F_{\text{net}}$ and $F_{\text{net}} = m_{\text{T}}a$ to calculate a. Then consider the forces on mass m_2. Use $F_{\text{TB}} = m_2a$ to calculate F_{TB}. Choose forwards as positive. So backwards is negative.

Solution:

$F_{net} = m_T a$

$F_{TA} = m_T a$

$$a = \frac{F_{TA}}{m_T} = \frac{+12 \text{ N}}{6.0 \text{ kg}}$$

$a = +2.0 \text{ m/s}^2$

$\vec{a} = 2.0 \text{ m/s}^2$ [forward]

For mass m_2, the net force acting is F_{TB}.

$F_{TB} = m_2 a$

$= (4.0 \text{ kg})(2.0 \text{ m/s}^2)$

$F_{TB} = 8.0 \text{ N}$

Statement: The acceleration is 2.0 m/s^2 [forwards] and the tension in string B is 8.0 N.

(b) Given: m_1 = 2.0 kg; m_2 = 4.0 kg; m_T = 2.0 kg + 4.0 kg = 6.0 kg; F_{TA} = 12 N [forwards]; μ_K = 0.10

Required: $\vec{a}$; $\vec{F}_{TB}$

Analysis: We can treat the two masses as a single object and use the equations $F_{net} = F_{TA} + F_f$ and $F_{net} = m_T a$ to calculate a. Then consider the forces on mass m_2. Use $F_{net} = F_{TB} + F_f$ to calculate F_{TB}. Choose forwards as positive. So backwards is negative.

Solution:

$F_{net} = F_{TA} + F_f$

$m_T a = F_{TA} - \mu_K F_N$

$m_T a = F_{TA} - \mu_K m_T g$

$(6.0 \text{ kg})a = +12 \text{ N} - (0.10)(6.0 \text{ kg})(9.8 \text{ m/s}^2)$

$a = +1.0 \text{ m/s}^2$

$\vec{a} = 1.0 \text{ m/s}^2$ [forward]

For mass m_2, the forces acting are F_{TB} and F_f.

$F_{net} = F_{TB} + F_f$

$m_2 a = F_{TB} - \mu_K F_N$

$F_{TB} = m_2 a + \mu_K F_N$

$= m_2 a + \mu_K m_2 g$

$= m_2 (a + \mu_K g)$

$= (4.0 \text{ kg})[(1.0 \text{ m/s}^2 + (0.10)(9.8 \text{ m/s}^2)]$

$F_{TB} = 8.0 \text{ N}$

Statement: The acceleration is 1.0 m/s^2 [forwards] and the tension in string B is 8.0 N.

(c) The acceleration of the masses in part (a) could be reduced to half in the presence of friction as the frictional force acting in the opposite direction is almost half the applied force. The tension in string B is not reduced very much since it is the result of both the net force and the frictional force. The smaller the frictional force, the greater is the acceleration (greater net force) so the magnitude of string B has not changed that much.

69. (a) Given: m_1 = 4.3 kg; m_2 = 5.5 kg; m_T = 4.3 kg + 5.5 kg = 9.8 kg; $\vec{F}_{pull}$ = 25 N [forwards]

Required: $\vec{a}$

Analysis: Since there are no other forces acting on the wagons, we can treat the two wagons as a single object and use the equations $F_{pull} = F_{net}$ and $F_{net} = m_T a$ to calculate a. Choose forwards as positive. So backwards is negative.

Solution:

$F_{net} = m_T a$

$F_{pull} = m_T a$

$$a = \frac{F_{pull}}{m_T} = \frac{+25 \text{ N}}{9.8 \text{ kg}}$$

$a = +2.6 \text{ m/s}^2$

$\vec{a} = 2.6 \text{ m/s}^2$ [forward]

Statement: The acceleration of both of the wagons is 2.6 m/s^2 [forwards].

(b) Given: m_1 = 4.3 kg; m_2 = 5.5 kg; $\vec{F}_{pull}$ = 25 N [forwards]

Required: F_{TA}; F_{TB}

Analysis: The net force on wagon 1 is the tension in rope A. Use $F_{TA} = m_1 a$ to calculate F_{TA}.

Solution:

$F_{TA} = m_1 a$

$= (4.3 \text{ kg})(2.55 \text{ m/s}^2)$

$F_{TA} = 11 \text{ N}$

The tension in rope B equals the magnitude of the pulling force. So, F_{TB} = 25 N.

Statement: The tension in rope A is 11 N and the tension in rope B is 25 N.

70. (a) Given: m_1 = 25 kg; m_2 = 45 kg; m_T = 25 kg + 45 kg = 70 kg

Required: $\vec{F}_{N1}$; $\vec{F}_{N2}$

Analysis: Since no other forces are acting, use $F_N = mg$ to calculate F_N.

Solution:
For box 1, the normal force is from box 2.

$$F_{N1} = m_1 g$$
$$= (25 \text{ kg})(9.8 \text{ m/s}^2)$$
$$F_{N1} = 250 \text{ N}$$

For box 2, the normal force is from the floor.

$$F_{N2} = m_T g$$
$$= (70 \text{ kg})(9.8 \text{ m/s}^2)$$
$$F_{N2} = 690 \text{ N}$$

Statement: The normal force on box 1 is 250 N [up] and on box 2 is 690 N [up].
(b) Given: m_1 = 25 kg; m_2 = 45 kg; m_T = 25 kg + 45 kg = 70 kg; $\vec{F}_{P1}$ = 55 N [up]
Required: $\vec{F}_{N1}$; $\vec{F}_{N2}$
Analysis: Consider the vertical forces acting. Since each box is not moving, the total of the forces in the vertical direction is zero. Use $F_N + F_g + F_a = 0$ to calculate F_N. Choose up as positive. So down is negative.
Solution:
For box 1, $\vec{F}_a$ = 55 N [up].

$$F_{N1} + m_1 g + F_{P1} = 0$$
$$F_{N1} + (25 \text{ kg})(-9.8 \text{ m/s}^2) + 55 \text{ N} = 0$$
$$F_{N1} = +190 \text{ N}$$
$$\vec{F}_{N1} = 190 \text{ N [up]}$$

For box 2, $\vec{F}_a$ = 55 N [up].

$$F_{N2} + m_T g + F_{P1} = 0$$
$$F_{N2} + (70 \text{ kg})(-9.8 \text{ m/s}^2) + 55 \text{ N} = 0$$
$$F_{N2} = +630 \text{ N}$$
$$\vec{F}_{N2} = 630 \text{ N [up]}$$

Statement: The normal force on box 1 is 190 N [up] and on box 2 is 630 N [up].
(c) Given: m_1 = 25 kg; m_2 = 45 kg; m_T = 25 kg + 45 kg = 70 kg; $\vec{F}_{P2}$ = 55 N [up]
Required: $\vec{F}_{N1}$; $\vec{F}_{N2}$
Analysis: Consider the vertical forces acting. Since each box is not moving, the total of the forces in the vertical direction is zero. Use $F_N + F_g + F_a = 0$ to calculate F_N. Choose up as positive. So down is negative.

Solution:
For box 1, $\vec{F}_a$ = 0.

$$F_{N1} + m_1 g = 0$$
$$F_{N1} + (25 \text{ kg})(-9.8 \text{ m/s}^2) = 0$$
$$F_{N1} = +250 \text{ N}$$
$$\vec{F}_{N1} = 250 \text{ N [up]}$$

For box 2, $\vec{F}_a$ = 55 N [up].

$$F_{N2} + m_T g + F_{P2} = 0$$
$$F_{N2} + (70 \text{ kg})(-9.8 \text{ m/s}^2) + 55 \text{ N} = 0$$
$$F_{N2} = +630 \text{ N}$$
$$\vec{F}_{N2} = 630 \text{ N [up]}$$

Statement: The normal force on box 1 is 250 N [up] and on box 2 is 630 N [up].
(d) Answers may vary. Sample answer:
The answers to (b) and (c) indicates that the change to the upward pull on the boxes affects the normal force of box 1 because the normal force on box 1 depends on the applied pulling force on it and is independent of the mass of box 2. The normal force on box 2 depends on the total mass of the two boxes and the total pulling force on either box. Since the total of these two are the same in (b) and (c), the normal force on box 2 is the same.
71. Given: m_1 = 15 kg; m_2 = 25 kg; μ_S = 0.45
Required: a
Analysis: The small block can accelerate at a maximum rate with the large block when the net force acting on it is equal to the maximum static friction between the blocks. Use the equations $F_S = \mu_s F_N$ and $F_{net} = ma$ to find a.
Solution:

$$F_{net} = F_S$$
$$ma = \mu_S F_N$$
$$ma = \mu_S mg$$
$$a = \frac{\mu_S mg}{m}$$
$$= \mu_S g$$
$$= (0.45)(9.8 \text{ m/s}^2)$$
$$a = 4.4 \text{ m/s}^2$$

Statement: The maximum acceleration the blocks can have is 4.4 m/s^2.
72. (a) Given: F_a = 250 N [forwards]; μ_K = 0.4; a = 0.88 m/s^2.
Required: m

Analysis: Use the equations $F_{net} = F_a + F_f$ and $F_{net} = ma$ to calculate *m*. Choose forwards as positive. So backwards is negative.

Solution:

$$\begin{aligned} F_{net} &= F_a + F_f \\ ma &= F_a - \mu_K F_N \\ ma &= F_a - \mu_K mg \\ ma + \mu_K mg &= F_a \\ m(a + \mu_K g) &= F_a \\ m &= \frac{F_a}{a + \mu_K g} \\ &= \frac{250\ \text{N}}{0.88\ \text{m/s}^2 + (0.4)(9.8\ \text{m/s}^2)} \\ &= 52\ \text{kg} \\ m &= 50\ \text{kg} \end{aligned}$$

Statement: The mass of the block is 50 kg.

(b) Given: $\vec{F}_a = 250$ N; $m = 52$ kg (one extra digit carried)

Required: μ_K

Analysis: Since the block is moving at a constant speed, $F_{net} = 0$. The magnitude of the applied force equals that of the kinetic friction.

Solution:

$$\begin{aligned} F_a &= F_K \\ F_a &= \mu_K F_N \\ F_a &= \mu_K mg \\ \mu_K &= \frac{F_a}{mg} \\ &= \frac{250\ \text{N}}{(52\ \text{kg})(9.8\ \text{m/s}^2)} \\ \mu_K &= 0.49 \end{aligned}$$

Statement: The coefficient of kinetic friction between the block and the new surface is 0.49.

73. Note: The given values for each team's applied force and μ_K were updated after the first printing. The solution below reflects these changes.

Given: $m_1 = 120$ kg; $F_1 = 420$ N; $m_2 = 130$ kg; $F_2 = 460$ N; $\mu_K = 0.30$

Required: a_1; a_2

Analysis: Use the equations $F_f = \mu_K F_N$ and $F_{net} = ma$ to determine the acceleration of each team.

Solution:

For team 1,

$$\begin{aligned} F_{net} &= F_1 - F_f \\ m_1 a_1 &= F_1 - \mu_K F_N \\ m_1 a_1 &= F_1 - \mu_K m_1 g \\ a_1 &= \frac{F_1 - \mu_K m_1 g}{m_1} \\ &= \frac{420\ \text{N} - (0.30)(120\ \text{kg})(9.8\ \text{m/s}^2)}{120\ \text{kg}} \\ a_1 &= 0.56\ \text{m/s}^2 \end{aligned}$$

For team 2,

$$\begin{aligned} F_{net} &= F_2 - F_f \\ m_2 a_2 &= F_2 - \mu_K F_N \\ m_2 a_2 &= F_2 - \mu_K m_2 g \\ a_2 &= \frac{F_2 - \mu_K m_2 g}{m_2} \\ &= \frac{460\ \text{N} - (0.30)(130\ \text{kg})(9.8\ \text{m/s}^2)}{130\ \text{kg}} \\ a_2 &= 0.60\ \text{m/s}^2 \end{aligned}$$

Statement: The acceleration of team 1 is 0.56 m/s^2 and that of team 2 is 0.60 m/s^2. So team 2 is faster.

74. (a) Given: $m = 72$ kg; $\mu_S = 0.80$

Required: *a*

Analysis: When walking without slipping, the maximum net force on the person equals the maximum static friction. Use $F_{net} = F_{S_{max}} = \mu_S F_N$ to calculate the maximum acceleration.

Solution:

$$\begin{aligned} F_{net} &= F_{S_{max}} \\ ma &= \mu_S F_N \\ a &= \mu_S g \\ &= (0.80)(9.8\ \text{m/s}^2) \\ a &= 7.8\ \text{m/s}^2 \end{aligned}$$

Statement: The acceleration of the person walking on concrete without slipping is 7.8 m/s^2.

(b) Given: $m = 72$ kg; $\mu_S = 0.075$

Required: *a*

Analysis: As in part (a), use $F_{net} = F_{S_{max}} = \mu_S F_N$ to calculate the maximum acceleration.

Solution:

$$\begin{aligned} F_{net} &= F_{S_{max}} \\ ma &= \mu_S F_N \\ a &= \mu_S g \\ &= (0.075)(9.8\ \text{m/s}^2) \\ a &= 0.74\ \text{m/s}^2 \end{aligned}$$

Statement: The acceleration of the person walking on ice without slipping is 0.74 m/s^2.

75. (a) Both blocks have the same normal force acting on them.

(b) For a square centimetre of surface in contact, the block with less surface area would have a stronger normal force since it has the same total force shared by less area.

(c) If you know the frictional force per area, multiply it by the total area to get the total frictional force.

(d) Answers may vary. Sample answer:
For the same frictional force, the force per area is small for an object with a large surface area in contact, but this large area has a small force acting on it. Conversely, for the same frictional force, an object with a small surface area in contact has a large force per area, but this force is acting on a small area. The total frictional force acting on the object in either case is the same. As a result, the frictional force acting on an object is independent of the surface area in contact.

76. Answers may vary. Sample answer:
Tread pattern could play a role in preventing hydroplaning. An example could be a tread pattern that sheds water away from the tire instead of requiring it to channel through the entire tread pattern.

77. Answers may vary. Students' answers should discuss a safety feature on a car and explain why they think it is the most important. Sample answer:
In my opinion, the most important safety device on a car is the seat belt. This works by using a pendulum so that when the car stops suddenly, the inertia from the pendulum causes it to swing and lock a gear in place. This holds the seat belt in place and keeps the passenger from flying out of the car. This is a relatively old device compared to the other safety features mentioned in the unit. There are not many ways for this to improve other than using different harness systems to distribute pressure from the belt across a larger area of the passenger.

Evaluation

78. Answers may vary. Sample answers:

(a) The government should pass the legislation because the use of a hand-held cellphone could cause distractions that increases the risk of losing control of the vehicle, a large number of car accidents have proved to be related to the use of cell-phones while driving, and the driver should pay full attention to operating the vehicle with his hands on the steering wheel instead of doing something else.

(b) This legislation would discourage the use of hand-held cellphones during driving and thus reduce the risks of distracted driving, which may cause serious car accidents and body injuries.

(c) I think this legislation is necessary as studies have shown that driving while talking on a cell phone also reduces a driver's response time to road conditions, another cause of major car accidents. Therefore, this legislation is very necessary.

79. Answers may vary. Sample answers:

(a) My favourite sport is soccer where the main action would be kicking and dribbling the ball. When kicking the ball, friction acts between the shoe and the ball. In this case more friction is desired. Increasing the friction between the shoe and the ball gives more control over the kick and prevents the ball from slipping out of control.

(b) The greatest force of friction comes from the ground and soccer cleats. This large amount of friction is highly desirable so that you do not slip and fall when running or kicking. The least amount of friction occurs between the ball and the grass. Here a moderate amount of friction is desired. With too much friction, the ball will slow down too fast, but with too little friction, the ball will get away from you, which makes it hard to control.

(c) Soccer cleats are used to create more friction. They have spikes on the bottom that dig into the ground to prevent you from slipping. The goalies also wear gloves that have a rubber coating on them. This helps them catch the ball when they are trying to make a save.

80. Answers may vary. Sample answers:

(a) In the human body, perhaps the most important type of bearing is our joints. Many of our joints such as the shoulders and hips are ball-in-socket type of joints, which compare to a ball bearing. Joints also use a fluid to help lubricate and reduce the friction between them, which could be compared to a type of fluid bearing. Our body also uses fluids such as cholesterol to help blood flow smoothly in the veins.

(b) Inside our bodies, there is not really anything that increases the amount of friction. However, on the outside of our bodies, our hands and feet are designed to increase the friction between contact surfaces. This helps grip things that are being picked up and helps prevent the feet from slipping. Fingerprints and footprints act much like the tread design on tires. Another body part that increases friction is the hair on our body. This is probably not designed to specifically increase friction but rather help provide insulation for the body. The hairs on nose and eyes slow down the air and help protect the nose and eyes from dust particles.

81. Answers may vary.

(a) Students' answers should include the knowledge gained from their research in Section 4.6 that helps them determine whether or not the costs of having snow tires are worth the safety the snow tires provide.

(b) Students' answers should include their thoughts about how the government could get involved and provide incentives for people to buy snow tires. They should discuss how this might save money, reducing the costs of emergency services for example, and how much this would cost. They should use this information to determine the action for the government.

Reflect on Your Learning

82. Answers may vary. Sample answer:
System diagrams give you a picture of the situation you are working with, but do not show any of the forces. They do however, give you a better idea of how the objects are interacting, which can help you draw a free-body diagram. Free-body diagrams show all of the forces acting on an object, but do not give you an idea of the situation. Free-body diagrams tend to be more useful though, since knowing the magnitude and directions of forces is what enables you to set up equations to solve the problem. It is possible to solve a problem if you are given a free-body diagram and the force values, but you cannot solve a problem with a system diagram alone. You would need to draw an FBD from the system diagram to solve the problem.

83. Answers may vary.

(a) Students' answers should reflect on the material they have learned and describe any sudden moments of insight they might have had when things started to make sense.

(b) Students' answers should discuss whether or not their understanding of the laws of kinematics has changed the way they view common occurrences and whether or not they think about the forces causing or reacting from them.

84. Answers may vary. Students' answers should discuss their understanding of friction and how their understanding has changed.

85. Answers may vary. Students' answers should explain that the safety features in a car do not make cars completely safe or accident resistant due to the different forces acting in different ways on the passengers.

Research

86. Answers may vary. Students' answers should discuss the causes of friction and may choose to describe how no surface is perfectly smooth, and how the molecules on a microscopic level run into each other and slow the motion down when surfaces are in contact with each other.

87. Answers may vary. Students' answers should discuss the topic of superfluids and how they act as if there is no friction. Superfluids are only possible at close to absolute zero temperatures and have the strange phenomena of being able to climb the walls of a container.

88. Answers may vary. Students' answers should discuss the speed-distance detection systems on cars and whether or not they are successful in preventing collisions.

89. Answers may vary. Students' answers should give a description of how a side curtain airbag works, when it is deployed, how it is different from a side airbag, and the safety standards that it is able to meet.

Unit 2 Self-Quiz, pages 206–207

1. (a)
2. (a)
3. (a)
4. (b)
5. (a)
6. (c)
7. (b)
8. (c)
9. (c)
10. (d)
11. (c)
12. (c)
13. (b)
14. (c)
15. (c)
16. (c)
17. False. A *free-body* diagram is a drawing of an object showing all the forces that are acting on it.
18. False. *An applied* force results when one object is in contact with another object and either pushes it or pulls on it.
19. False. *Newton* formulated the modern laws of force and motion that helped define the science of dynamics.
20. True
21. False. A car will have *more* inertia than a bicycle if the car is moving fast.
22. False. An object can travel *at a constant velocity* even if the net force the object experiences is zero.
23. True
24. True
25. False. When your foot pushes off the floor to walk, the floor is pushing back on your foot *with an equal* force.
26. True
27. False. When a skydiver has accelerated to the point when the force of gravity pulling down on her equals the air resistance pushing up, she has reached *terminal* speed.
28. True
29. False. The coefficient of *kinetic* friction is the ratio of the friction force on a moving object to the normal force acting on the object.
30. False. If an object has a mass of 10 kg and experiences a maximum static frictional force of 49 N, then the coefficient of static friction between the object and the surface is *0.5*.
31. False. If the coefficient of kinetic friction for a horizontal surface is 0.40, then an object weighing 10 N will require *4.0 N* of force to remain in motion.
32. True
33. True
34. False. *Unlike* antilock braking systems, traction control is used when the car is *speeding up* and the tires start skidding.
35. True
36. False. *Snow* tires have a special symbol that distinguishes them from *all-season* tires.

Unit 2: Unit Task, page 205

Analyze and Evaluate

(a) Answers may vary. Students' answers should be similar to the following: The force of friction acting on the cart tires depends on the surface area the tires come into contact. The force of friction on the tires going over a rough surface would be greater than the force of friction on the tires going over a smooth surface. The greater the force of friction, the slower the motion of the cart. The force of friction also depends on mass. The greater the mass, the greater the force of friction.
(b) Answers may vary. Students should discuss the mass of the materials used, the shock absorbing ability of the bumper material, smoothness of the surface the cart rolled over, and techniques for fastening the egg to the cart.
(c) Answers may vary. Students should describe each trial, the results, the problems, and what was done to correct the problem in the next trial.
(d) Posters should be displayed using photographs of the cart in motion, images of various bumpers and the materials could be provided or the bumpers themselves. Images of the cart with the various bumpers should be provided. A table or other graphic organizer summarizing their results should be provided.

Apply and Extend

(e) Answers may vary. Students should provide a list of similarities and differences between their designs and with other identified groups.
(f) Answers may vary. Some possible answers are making the bumper extend further out/ahead of the cart, using a more shock absorbing material (such as foamy rubber, bubble wrap, or flexible plastic bands), rounding out the shape of the bumper so the area the bumper contacts with the wall is reduced.