3 Forces

3-1 Forces and Acceleration

Vocabulary **Force:** A push or a pull.

When an unbalanced force is exerted on an object, the object accelerates in the direction of the force. The acceleration is proportional to the force and inversely proportional to the mass of the object. This is Newton's second law and it can be represented with an equation that says

force = (mass)(acceleration) or $F = ma$

The unbalanced force is called the **net force,** or resultant of all the forces acting on the system.

The SI unit for force is the **newton,** which equals one **kilogram meter per second squared** ($\mathbf{N = kg \cdot m/s^2}$).

You can think of a newton as being about equivalent to the weight of a stick of butter.

Mass, or the amount of matter in an object, does not change regardless of where an object is located. It is a constant property of any object. However, do not confuse mass with **weight!** The weight of an object is simply the gravitational force acting on the object. Therefore, if an object is moved away from Earth to a location where g is no longer 10.0 m/s^2, the object will no longer have the same weight as it did on Earth. The equation for weight is just a specific case of $F = ma$.

weight = (mass)(acceleration due to gravity) or $w = mg$

Because of its weight, an object pushes against a surface on which it lies. By Newton's third law, the surface pushes back on the object. This push, which is called the **normal force,** is always perpendicular to the surface on which the object rests.

Some of the exercises you will do in this chapter require the use of some basic trigonometry. If you would like a review of trigonometry, refer to Appendix A.

Solved Examples

Example 1: Felicia, the ballet dancer, has a mass of 45.0 kg. a) What is Felicia's weight on Earth? b) What is Felicia's mass on Jupiter, where the acceleration due to gravity is 25.0 m/s^2? c) What is Felicia's weight on Jupiter?

Solution: a. Felicia's weight on Earth depends upon the gravitational pull of the earth on Felicia's mass.

Given: $m = 45.0\text{ kg}$
$g = 10.0\text{ m/s}^2$

Unknown: $w = ?$
Original equation: $w = mg$

Solve: $w = mg = (45.0\text{ kg})(10.0\text{ m/s}^2) = \mathbf{450.\ N}$

b. The mass of an object remains the same whether the object is on Earth, in space, or on another planet. Therefore, on Jupiter, Felicia's mass is still 45.0 kg.

c. The acceleration due to gravity on Jupiter is 25.0 m/s^2.

Given: $m = 45.0\text{ kg}$
$g = 25.0\text{ m/s}^2$

Unknown: $w = ?$
Original equation: $w = mg$

Solve: $w = mg = (45.0\text{ kg})(25.0\text{ m/s}^2) = \mathbf{1130\ N}$

Since a newton is equivalent to 0.22 pounds, little Felicia would weigh about 260 lb on Jupiter. It should be noted, however, that it would be impossible to stand on Jupiter due to its entirely gaseous surface.

Example 2: Butch, the 72.0-kg star quarterback of Belmont High School's football team, collides with Trask, a stationary left tackle, and is brought to a stop with an acceleration of -20.0 m/s^2. a) What force does Trask exert on Butch? b) What force does Butch exert on Trask?

Solution: a. The force depends upon the rate at which Butch's mass is brought to rest.

Given: $m = 72.0\text{ kg}$
$g = -20.0\text{ m/s}^2$

Unknown: $F = ?$
Original equation: $F = ma$

Solve: $F = ma = (72.0\text{ kg})(-20.0\text{ m/s}^2) = \mathbf{-1440\ N}$

The negative sign in the answer implies that the direction of the force is opposite that of Butch's original direction of motion.

b. Newton's third law states that for every action there is an equal and opposite reaction. Therefore, if Trask exerts a force of -1440 N on Butch, Butch will exert the same **1440 N** force back on Trask, but in the opposite direction.

Example 3: A 20-g sparrow flying toward a bird feeder mistakes the pane of glass in a window for an opening and slams into it with a force of 2.0 N. What is the bird's acceleration?

Solution: Since the sparrow exerts 2.0 N of force on the window, the window must provide −2.0 N back in the opposite direction. Don't forget to convert grams into kilograms before beginning.

$$20 \text{ g} = 0.02 \text{ kg}$$

For a review of unit conversions, see Appendix A.

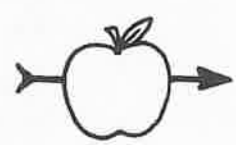
Given: $m = 0.02$ kg
$F = -2.0$ N

Unknown: $a = ?$
Original equation: $F = ma$

Solve: $a = \frac{F}{m} = \frac{-2.0 \text{ N}}{0.02 \text{ kg}} = \mathbf{-100\ m/s^2}$ (about 10 g's!)

Therefore, the bird experiences a very rapid negative acceleration, as the window brings the bird to a sudden stop. Ouch!

Example 4: A 30.0-g arrow is shot by William Tell through an 8.00-cm-thick apple sitting on top of his son's head. If the arrow enters the apple at 30.0 m/s and emerges at 25.0 m/s in the same direction, with what force has the apple resisted the arrow?



Solution: First, convert g to kg and cm to m.

$$30.0 \text{ g} = 0.0300 \text{ kg} \qquad 8.00 \text{ cm} = 0.0800 \text{ m}$$

Next, find the acceleration of the arrow before finding the force.

Given: $v_o = 30.0$ m/s
$v_f = 25.0$ m/s
$\Delta d = 0.0800$ m

Unknown: $a = ?$
Original equation: $v_f^2 = v_o^2 + 2a\Delta d$

Solve: $a = \frac{v_f^2 - v_o^2}{2\Delta d} = \frac{(25.0 \text{ m/s})^2 - (30.0 \text{ m/s})^2}{2(0.0800 \text{ m})} = \frac{625 \text{ m}^2/\text{s}^2 - 900. \text{ m}^2/\text{s}^2}{0.160 \text{ m}}$

$= -1720 \text{ m/s}^2$

The negative sign before the answer implies that the apple was causing the arrow to slow down. Now solve for the force exerted by the apple.

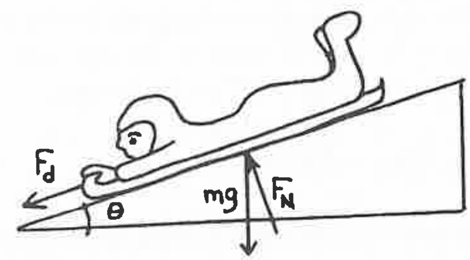
Given: $m = 0.0300$ kg
$a = -1720 \text{ m/s}^2$

Unknown: $F = ?$
Original equation: $F = ma$

Solve: $F = ma = (0.0300 \text{ kg})(-1720 \text{ m/s}^2) = \mathbf{-51.6\ N}$

This is the force that the apple exerts on the arrow. It is negative because its direction is opposite to the arrow's direction of motion.

Example 5: Rose is sledding down an ice-covered hill inclined at an angle of 15° with the horizontal. If Rose and the sled have a combined mass of 54.0 kg, what is the force pulling them down the hill?

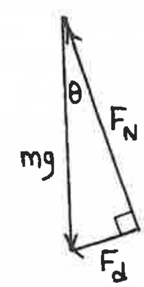


Solution: This exercise is a bit more complex than the preceding examples. Before beginning the solution, look at all the forces on the sled.

a. First, there is the **gravitational force,** which always acts downward. This is the weight of the sled. It is labeled ***mg***.

b. The next force to be considered is the **normal force.** This force always acts perpendicular to the surface, so it pushes against the bottom of the sled. It is labeled F_N.

c. The resultant of these forces is a **component of the gravitational force** that goes in the direction of the motion of the sled, or down the slope. It is labeled F_d.



You can redraw these three forces as a right triangle. The angle of the slope corresponds to the angle between mg and F_N. Now with the use of trigonometry, you can solve for the force down the incline, F_d.

Given: $m = 54.0$ kg
$g = 10.0\ \text{m/s}^2$
$\theta = 15°$

Unknown: $F_d = ?$
Original equation: $\sin\theta = \dfrac{\text{opp}}{\text{hyp}} = \dfrac{F_d}{mg}$

Solve: $F_d = mg\sin\theta = (54.0\ \text{kg})(10.0\ \text{m/s}^2)\sin 15° = 140\ \text{N}$

Practice Exercises

Exercise 1: You can find your own mass in kg with the following information: 1.0 kg weighs about 2.2 lb on Earth. a) What is your mass in kg? b) What is your weight in newtons?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 2: Gunter the weightlifter can lift a 230.0-kg barbell overhead on Earth. The acceleration due to gravity on the sun is 274 m/s^2. a) Would the barbells be heavier on the sun or on Earth? b) How much (in newtons) would the barbells weigh on the sun (if it were possible to stand on the sun without melting)?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 3: Sammy Sosa swings at a 0.15 kg baseball and accelerates it at a rate of 3.0×10^4 m/s^2. How much force does Sosa exert on the ball?

Answer: ____________________

Exercise 4: Claudia stubs her toe on the coffee table with a force of 100. N. a) What is the acceleration of Claudia's 1.80-kg foot? b) What is the acceleration of the table if it has a mass of 20.0 kg? (Ignore any frictional effects.) c) Why would Claudia's toe hurt less if the table had less mass?

Answer: **a.** ______________

Answer: **b.** ______________

Answer: **c.** ______________

Exercise 5: While chopping down his father's cherry tree, George discovered that if he swung the axe with a speed of 25 m/s, it would embed itself 2.3 cm into the tree before coming to a stop. a) If the axe head had a mass of 2.5 kg, how much force was the tree exerting on the axe head upon impact? b) How much force did the axe exert back on the tree?

Answer: **a.** ______________

Answer: **b.** ______________

Exercise 6: Carter's favorite ride at Playland Amusement Park is the rollercoaster. The rollercoaster car and passengers have a combined mass of 1620 kg, and they descend the first hill at an angle of 45.0° to the horizontal. With what force is the rollercoaster pulled down the hill?

Answer: ______________

3-2 Friction

Vocabulary **Friction:** The force that acts to oppose the motion between two materials moving past each other.

There are many types of friction between surfaces. They include

Static friction: The resistance force that must be overcome to start an object in motion.

Kinetic or sliding friction: The resistance force between two surfaces already in motion.

Rolling friction: The resistance force between a surface and a rolling object.

Fluid friction: The resistance force of a gas or a liquid as an object passes through. One example of fluid friction is air resistance.

In this chapter, we will deal only with kinetic or sliding friction.

The force of sliding friction between two surfaces depends on the normal force pressing the surfaces together, and on the types of surfaces that are in contact with each other. The magnitude of this force is written as

force of sliding friction = (coefficient of sliding friction)(normal force)

or $F_f = \mu F_N$

If an object is sitting on a horizontal surface, the normal force is equal to the weight of the object. The symbol μ (pronounced "mu") is called the **coefficient of sliding friction.** A high coefficient of friction (in other words, a large number for μ) means that the object is not likely to slide easily, while a low coefficient of friction (or a small μ) is found between very slippery surfaces. Because the coefficient of sliding friction is simply a ratio of the force of sliding friction to the normal force, it has no units.

Solved Examples

Example 6: Brian is walking through the school cafeteria but does not realize that the person in front of him has just spilled his glass of chocolate milk. As Brian, who weighs 420 N, steps in the milk, the coefficient of sliding friction between Brian and the floor is suddenly reduced to 0.040. What is the force of sliding friction between Brian and the slippery floor?

Solution: In order to find the force of sliding friction, you need to know the normal force, or the force the ground exerts upward on Brian. On a horizontal surface this normal force is equivalent to the object's weight, which in this case is 420 N.

Given: $F_N = 420$ N, $\mu = 0.040$

Unknown: $F_f = ?$

Original equation: $F_f = \mu F_N$

Solve: $F_f = \mu F_N = (0.040)(420 \text{ N}) = \mathbf{17\ N}$

Example 7: While redecorating her apartment, Kitty slowly pushes an 82-kg china cabinet across the wooden dining room floor, which resists the motion with a force of friction of 320 N. What is the coefficient of sliding friction between the china cabinet and the floor?

Solution: As in the previous exercise, the normal force is equivalent to the weight of the china cabinet because the cabinet is sitting on a horizontal surface.

Given: $m = 82$ kg, $g = 10.0 \text{ m/s}^2$

Unknown: $w = ?$

Original equation: $w = mg$

Solve: $w = mg = (82 \text{ kg})(10.0 \text{ m/s}^2) = 820 \text{ N}$ so F_N is also 820 N.

Given: $F_N = 820$ N, $F_f = 320$ N

Unknown: $\mu = ?$

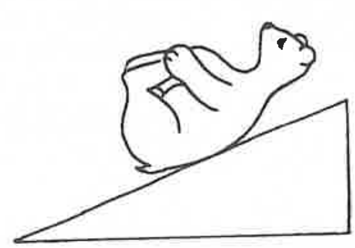
Original equation: $F_f = \mu F_N$

Solve: $\mu = \dfrac{F_f}{F_N} = \dfrac{320 \text{ N}}{820 \text{ N}} = \mathbf{0.39}$

Remember, μ has no units!

Example 8: At Sea World, a 900.-kg polar bear slides down a wet slide inclined at an angle of 25.0° to the horizontal. The coefficient of friction between the bear and the slide is 0.0500. What frictional force impedes the bear's motion down the slide?

Solution: In this example, unlike the previous ones in this section, the polar bear is inclined at an angle to the horizontal so you must find the normal force on the polar bear by using the cosine of this angle. Remember, the normal force, F_N, always acts perpendicular to the surface on which the object is moving.



Given: $m = 900.$ kg, $g = 10.0 \text{ m/s}^2$, $\theta = 25.0°$

Unknown: $F_N = ?$

Original equation: $\cos\theta = \dfrac{\text{adj}}{\text{hyp}} = \dfrac{F_N}{mg}$

Solve: $F_N = mg\cos\theta = (900. \text{ kg})(10.0 \text{ m/s}^2)\cos 25.0° = 8160 \text{ N}$

Given: $F_N = 8160$ N, $\mu = 0.0500$

Unknown: $F_f = ?$

Original equation: $F_f = \mu F_N$

Solve: $F_f = \mu F_N = (0.0500)(8160 \text{ N}) = \mathbf{408\ N}$

Practice Exercises

Exercise 7: Unbeknownst to the students, every time the school floors are waxed, Mr. Tracy, the principal, likes to slide down the hallway in his socks. Mr. Tracy weighs 850. N and the coefficient of sliding friction between his socks and the floor is 0.120. What is the force of friction that opposes Mr. Tracy's motion down the hall?

Answer: ____________________

Exercise 8: Skye is trying to make her 70.0-kg Saint Bernard go out the back door but the dog refuses to walk. If the coefficient of sliding friction between the dog and the floor is 0.50, how hard must Skye push in order to move the dog with a constant speed?

Answer: ____________________

Exercise 9: Rather than taking the stairs, Martin gets from the second floor of his house to the first floor by sliding down the banister that is inclined at an angle of 30.0° to the horizontal. a) If Martin has a mass of 45 kg and the coefficient of sliding friction between Martin and the banister is 0.20, what is the force of friction impeding Martin's motion down the banister? b) If the banister is made steeper (inclined at a larger angle), will this have any effect on the force of friction? If so, what?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 10: As Alan is taking a shower, the soap falls out of the soap dish and Alan steps on it with a force of 500 N. If Alan slides forward and the frictional force between the soap and the tub is 50 N, what is the coefficient of friction between these two surfaces?

Answer: ______________

Exercise 11: Howard, the soda jerk at Bea's diner, slides a 0.60-kg root beer from the end of the counter to a thirsty customer. A force of friction of 1.2 N brings the drink to a stop right in front of the customer. a) What is the coefficient of sliding friction between the glass and the counter? b) If the glass encounters a sticky patch on the counter, will this spot have a higher or lower coefficient of friction?

Answer: **a.** ______________

Answer: **b.** ______________

3-3 Statics

Vocabulary

Statics: The study of forces in equilibrium.

When forces are in **equilibrium,** all the forces acting on a body are balanced, and the body is not accelerating. In order to solve statics exercises, you must study all the forces acting on an object in the horizontal or x-direction separately from all the forces acting in the vertical or y-direction. This means that you must take the horizontal and vertical components of these forces. Because the object is not accelerating, the sum of all the horizontal components must equal zero and the sum of all the vertical components must equal zero. Rules for finding horizontal and vertical components are found in Appendix A.

A few hints: In statics exercises, you may frequently see the term **tension.** Tension is the force that is exerted by a rope or a wire, or any object that pulls on another. It has the same units as any other force.

You will notice that there are several exercises here that involve objects hanging from wires. Whenever this situation occurs, the sum of the vertical components of the tension in each wire is equal to the object's weight. If the object hangs in the middle of two equal-length wires, the weight is shared equally by each wire.

Solved Examples

Example 9: Flip, an exhausted gymnast, hangs from a bar by both arms in an effort to catch his breath. If Flip has a mass of 65.0 kg, what is the tension in each of Flip's arms as he hangs in place?

Solution: First find Flip's weight.

Given: $m = 65.0$ kg
$g = 10.0 \text{ m/s}^2$

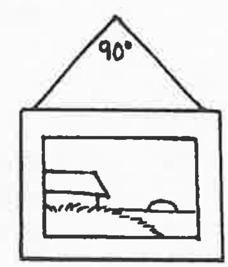
Unknown: $w = ?$
Original equation: $w = mg$

Solve: $w = mg = (65.0 \text{ kg})(10.0 \text{ m/s}^2) = 650. \text{ N}$

Since Flip is pulling down on the bar with a force of 650. N, his arms must be holding him up by sharing an upward force of 650. N. If each of Flip's arms shares the force equally, then each must provide a tension of **325 N.**

Example 10: At an art auction, Whitney has acquired a painting that now hangs from a nail on her wall, as shown in the figure. If the painting has a mass of 12.6 kg, what is the tension in each side of the wire supporting the painting?

Solution: The weight of the painting is shared equally by two wires, so each wire must support only half of the weight. However, in this example the wires do not hang vertically, but instead act at an angle with the painting. Therefore, you must use trigonometry to find the actual tension in the wire.

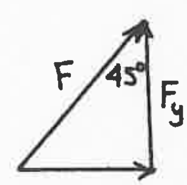


Given: $m = 12.6$ kg
$g = 10.0 \text{ m/s}^2$

Unknown: $w = ?$
Original equation: $w = mg$

Solve: $w = mg = (12.6 \text{ kg})(10.0 \text{ m/s}^2) = 126 \text{ N}$

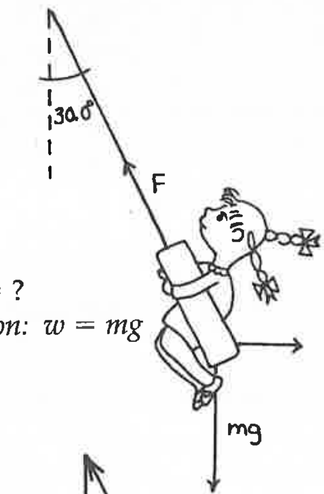
Therefore, each of the wires equally shares 63 N. Call this value F_y, and use trigonometry to find the angle.



$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{F_y}{F} \qquad F = \frac{F_y}{\cos\theta} = \frac{63 \text{ N}}{\cos 45°} = \frac{63 \text{ N}}{0.71} = \mathbf{89\ N}$$

Therefore, each wire holds the painting with a tension or force of 89 N.

Example 11: Michelle likes to swing on a tire tied to a tree branch in her yard, as in the figure. a) If Michelle and the tire have a combined mass of 82.5 kg, and Elwin pulls Michelle back far enough for her to make an angle of 30.0° with the vertical, what is the tension in the rope supporting Michelle and the tire?

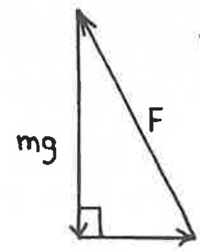


Given: $m = 82.5$ kg
$g = 10.0\ \text{m/s}^2$

Unknown: $w = ?$
Original equation: $w = mg$

Solve: $w = mg = (82.5\ \text{kg})(10.0\ \text{m/s}^2) = 825\ \text{N}$

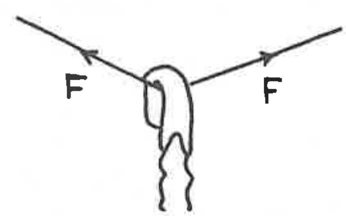
First, redraw the forces so that they are connected head to tail in a triangle. This allows you to use rules of trigonometry to solve for the tension, *F*.



$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{mg}{F}$$

$$F = \frac{mg}{\cos\theta} = \frac{825\ \text{N}}{\cos 30.0°} = \frac{825\ \text{N}}{0.866} = \mathbf{953\ N}$$

Example 12: After returning home from the beach, Samantha hangs her wet 0.20-kg bathing suit in the center of the 6.0-m-long clothesline to dry. This causes the clothesline to sag 4.0 cm. What is the tension in the clothesline?



Solution: First, convert cm to m.

4.0 cm = 0.040 m

Because the bathing suit is hung in the center of the clothesline, the tension in each side of the line is the same. You must find the downward force on the clothesline, which is simply the weight of the bathing suit.

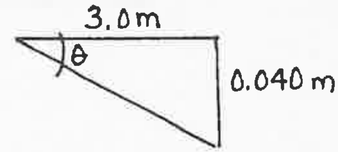
Given: $m = 0.20$ kg
$g = 10.0\ \text{m/s}^2$

Unknown: $w = ?$
Original equation: $w = mg$

Solve: $w = mg = (0.20\ \text{kg})(10.0\ \text{m/s}^2) = 2.0\ \text{N}$

Half of this force, 1.0 N, will pull on the left side of the clothesline and half will pull on the right, *only* because the bathing suit hangs in the middle of the line.

Before you can calculate the tension, *F*, in the rope, you need to determine the angle the clothesline makes with the horizontal. To do this, use the known distances of 3.0 m and 0.040 m as shown in the diagram. This diagram is not drawn to scale.



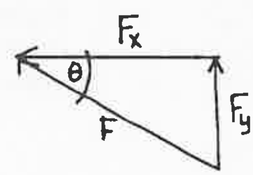
(Not drawn to scale)

$$\tan\theta = \frac{\text{opp}}{\text{adj}} = \frac{d_y}{d_x} = \frac{0.040\text{ m}}{3.0\text{ m}} = 0.013$$

Taking the inverse of the tangent gives the angle,

$$\tan^{-1} 0.013 = \theta \qquad \text{so} \qquad \theta = 0.74°$$

The angle is 0.74° and the bathing suit causes the clothesline to pull up with a force of 1.0 N. Now find the tension in the line. Again, this is done using trigonometry, because the angle and the vertical component of the force are known.



$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{F_y}{F}$$

$$F = \frac{F_y}{\sin\theta} = \frac{1.0\text{ N}}{\sin 0.74°} = \frac{1.0\text{ N}}{0.013} = \mathbf{77\ N}$$

The tension in each side of the clothesline is 77 N.

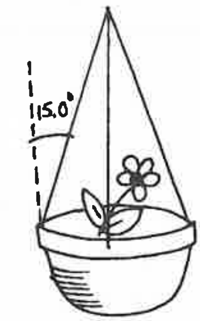
Practice Exercises

Exercise 12: While moving out of her dorm room, Bridget carries a 12-kg box to her car, holding it in both arms. a) How much force must be exerted by each of her arms to support the box? b) How will this force change if Bridget holds the box with only one arm?

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 13: A flower pot of mass 4.20 kg is hung above a window by three ropes, each making an angle of 15.0° with the vertical, as shown. What is the tension in each rope supporting the flower pot?

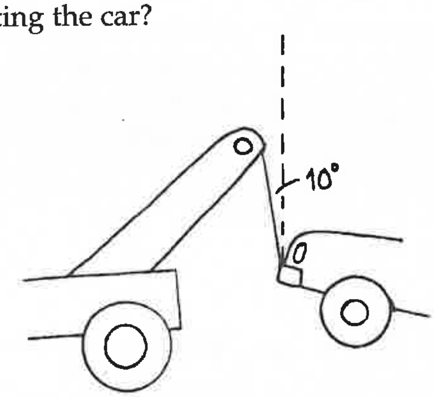


Answer: ____________________

Exercise 14: Luke Skywalker must swing Princess Leia across a large chasm in order to escape the Storm Troopers. If Luke and Leia's combined mass is 145 kg, calculate the tension in the rope just before Luke and Leia start their swing, when the pair makes an angle of 30.0° with the vertical.

Answer: ____________________

Exercise 15: The ACE towing company tows a disabled 1050-kg automobile off the road at a constant speed. If the tow line makes an angle of 10.0° with the vertical as shown, what is the tension in the line supporting the car?



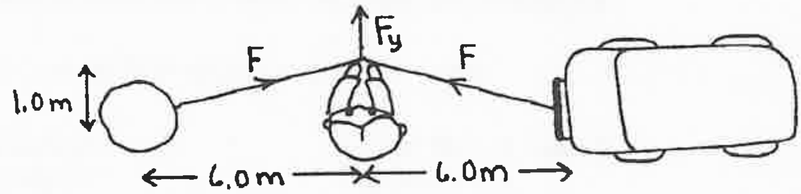
Answer: ____________________

Exercise 16: Yvette hangs a 2.4-kg bird feeder in the middle of a rope tied between two trees. The feeder creates a tension of 480 N in each side of the the rope.
a) If the two trees are 4.0 m apart, how much will the rope sag in the center?
b) If a bird lands on the feeder, will this have any effect on the tension in the rope? Explain.

Answer: **a.** ____________________

Answer: **b.** ____________________

Exercise 17: After pulling his car off to the side of the road during a rainstrom, Travis is dismayed to find that the car has become stuck in the mud. Travis ties one end of a rope to the front of the car and the other end to a tree 12.00 m away as shown. a) If Travis can exert a force of 610 N on the rope, moving it 1.00 m in the direction shown, how much force will the rope exert on the car? b) Why is this method better than simply tying a rope to the front of the car and pulling the car straight out?



Answer: **a.** ____________________

Answer: **b.** ____________________

3-4 Pressure

Vocabulary **Pressure:** The force per unit area.

$$\textbf{pressure} = \frac{\textbf{force}}{\textbf{area}} \quad \text{or} \quad P = \frac{F}{A}$$

The SI unit for pressure is the **pascal,** which equals one **newton per square meter (P = N/m²).**

It is very easy to confuse pressure with force. While force is a push or a pull, pressure is a push or pull on a certain area. For a given force, the pressure due to that force is inversely proportional to the area on which the force is exerted. Therefore, if the area of contact is small, the amount of pressure between two surfaces is much greater than if the force were exerted over a larger area.

For example, place a pencil between the palms of your hands with the pointed end pushing against one palm and the eraser end against the other. As you squeeze your hands together, you will feel a much more unpleasant sensation at the pencil tip than at the eraser! The eraser has a larger area, so the force is spread out more evenly over the nerve endings of your hand.

Solved Examples

Example 13: Brooke comes home from school and puts her books down on the kitchen table while she goes to grab a snack. The books have a combined weight of 25 N and the area of contact is 0.19 m by 0.24 m. What pressure do the books apply on the table?

Solution: First, find the area of the surface that is pressing down on the table.

$$\text{area} = \text{length} \times \text{width} = 0.19\ \text{m} \times 0.24\ \text{m} = 0.046\ \text{m}^2$$

Given: $F = 25\ \text{N}$
$A = 0.046\ \text{m}^2$

Unknown: $P = ?$
Original equation: $P = \frac{F}{A}$

Solve: $P = \frac{F}{A} = \frac{25\ \text{N}}{0.046\ \text{m}^2} = \mathbf{540\ \frac{N}{m^2}}$

Example 14: A full coffee mug has a mass of 0.60 kg and an empty mug has a mass of 0.30 kg. a) Which mug, the full one or the empty one, applies a greater pressure on the table? b) If the full mug applies a pressure of 1200. N/m², what is the area inside a circular ring of coffee left on the table by the bottom of the mug? c) What is the radius of the ring of coffee?

a. The full mug applies more pressure because a larger force is spread over the given area.

b. The force exerted by the full mug is its weight.

$$w = mg = (0.60\ \text{kg})(10.0\ \text{m/s}^2) = 6.0\ \text{N}$$

Given: $F = 6.0\ \text{N}$
$P = 1200.\ \text{N/m}^2$

Unknown: $A = ?$
Original equation: $P = \dfrac{F}{A}$

Solve: $A = \dfrac{F}{P} = \dfrac{6.0\ \text{N}}{1200.\ \text{N/m}^2} = \mathbf{0.0050\ m^2}$

c. To find the radius, use the equation for the area of a circle.

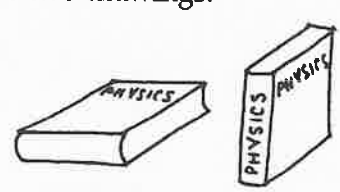
Given: $A = 0.0050\ \text{m}^2$
$\pi = 3.14$

Unknown: $r = ?$
Original equation: $A = \pi r^2$

Solve: $r = \sqrt{\dfrac{A}{\pi}} = \sqrt{\dfrac{0.0050\ \text{m}^2}{3.14}} = \mathbf{0.040\ m}$

Practice Exercises

Exercise 18: a) Which exerts a greater force on a table, a 1.70-kg physics book lying flat on the table, or a 1.70-kg physics book standing on end on the table? b) Which applies a greater pressure? c) If each book measures 0.260 m × 0.210 m × 0.040 m, calculate the pressure applied in each of these two drawings.



Answer: **a.** ____________________

Answer: **b.** ____________________

Answer: **c.** ____________________

Exercise 19: Miss Culp, a high school English teacher, marches next to Miss Vance, a physics teacher, in the graduation procession across the football field. Each woman has a mass of 60.0 kg, but Miss Culp is wearing spike heels that have an area of 0.40 cm^2 while Miss Vance wears wide heels with an area of 6.0 cm^2. a) Calculate how much pressure each woman will apply on the ground. b) What could Miss Culp do, while she walks, to help her sink less into the ground?

Answer: **a.** ______________________

Answer: **b.** ______________________

Exercise 20: Morgan has a mass of 85 kg and is on top of a bed in such a position that she can apply a pressure of 9530 N/m^2 on the mattress. Would you calculate that Morgan is standing, sitting, or lying on the bed?

Answer: ______________________

Exercise 21: Caleb is filling up water balloons for the Physics Olympics balloon toss competition. Caleb sets a 0.50-kg spherical water balloon on the kitchen table and notices that the bottom of the balloon flattens until the pressure on the bottom is reduced to 630 N/m^2. a) What is the area of the flat spot on the bottom of the balloon? b) What is the radius of the flat spot?

Answer: **a.** ______________________

Answer: **b.** ______________________

Additional Exercises

A-1: What is the minimal force a mother must exert to lift her 5.0-kg baby out of its crib?

A-2: On the moon, the gravity is 1/6 that of Earth. While on the moon, Buzz Aldrin carried on his back a support system that would weigh over 1760 N on Earth. a) What did the backpack weigh on the moon? b) What was its mass on the moon?

A-3: A common malady in runners who run on too hard a surface is shin splints. If a runner's 7.0-kg leg hits the pavement so that it comes to rest with an acceleration of $-200.0\ m/s^2$ on each hit, how much force must the runner's leg withstand on each step?

A-4: In the district soccer championship finals, Elizabeth kicks a 0.600-kg soccer ball with a force of 80.0 N. How much does she accelerate the soccer ball from rest in the process?

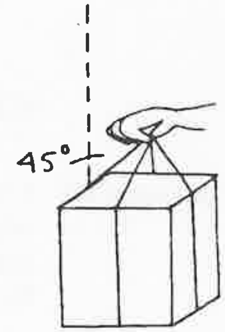
A-5: Barker is unloading 20-kg bottles of water from this delivery truck when one of the bottles tips over and slides down the truck ramp that is inclined at an angle of 30° to the ground. What amount of force moves the bottle down the ramp?

A-6: Sarah, whose mass is 40.0 kg, is on her way to school after a winter storm when she accidentally slips on a patch of ice whose coefficient of sliding friction is 0.060. What force of friction will eventually bring Sarah to a stop?

A-7: In her physics lab, Molly puts a 1.0-kg mass on a 2.0-kg block of wood. She pulls the combination across another wooden board with a constant speed to determine the coefficient of sliding friction between the two surfaces. If Molly must pull with a force of 6.0 N, what coefficient of sliding friction does she calculate for wood on wood?

A-8: A 1250-kg slippery hippo slides down a mud-covered hill inclined at an angle of 18.0° to the horizontal. a) If the coefficient of sliding friction between the hippo and the mud is 0.0900, what force of friction impedes the hippo's motion down the hill? b) If the hill were steeper, how would this affect the coefficient of sliding friction?

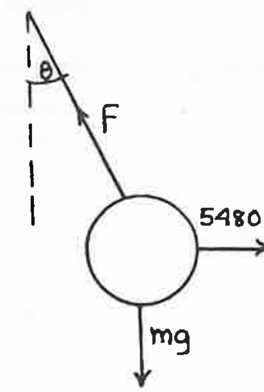
A-9: Erma receives a 5.00-kg package in the mail tied with a string that goes around each side of the box, as shown. If Erma lifts the box by the string in the center so that each piece of string makes an angle of 45.0° with the vertical, what is the tension in each piece of string?



A-10: To make extra money during the summer, Mr. Garber, a 66.0-kg physics teacher, paints the outside of houses while sitting on a 4.0-kg plank suspended by two vertical cables. What is the tension in each of the two cables?

A-11: While camping in Denali National Park in Alaska, a wise camper hangs his pack of food from a rope tied between two trees, to keep the food away from the bears. If the 5.0-kg bag of food hangs from the center of a rope that is 3.0 m long, and the rope sags 6.0 cm in the middle, what is the tension in the rope?

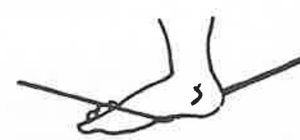
A-12: In the figure, a 1240-kg wrecking ball is pulled back with a horizontal force of 5480 N before being swung against the side of a building. a) What angle does the wrecking ball make with the vertical when it is pulled back? b) What is the tension in the ball's supporting cable when it is at this angle?



A-13: What force must you exert on a ball point pen in order to apply a pressure of 0.067 N/mm^2 on a piece of paper, if the ball of the pen has a surface area of 1.2 mm^2 touching the paper?

A-14: Asad cuts his knee in a fall while chasing a soccer ball. If a 6-N force is exerted on Asad's knee during the fall, applying a pressure of 1000 N/m^2 on an area of his skin, what is the area of the cut that results from the impact?

A-15: The amazing Gambini walks across a 30.0-m-long tightrope high above a 3-ring circus. a) If the 75.0-kg Gambini pushes the tightrope down 15.0 cm in the center, find the tension in the tightrope. b) If a 10-cm^2 area of Gambini's foot presses on the rope, how much pressure does Gambini apply on this area?

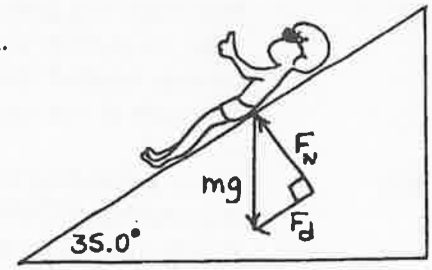


A-16: In the TV show, *The Addams Family,* Uncle Fester found it quite comfortable to sleep on a bed of nails. Though this doesn't sound like the most pleasant way to take a nap, it is not too painful if many nails are placed fairly close together. a) If Uncle Fester has a mass of 53 kg and his body covers 700 nails, each with a surface area of 1.00 mm^2, what is the pressure exerted on his body? b) What would be the pressure if Uncle Fester napped on a bed made of only 1 nail?

Challenge Exercises for Further Study

Example 15: Linc, the 65.0-kg lifeguard, slides down a water slide that is inclined at an angle of 35.0° to the horizontal, into the community swimming pool. If the coefficient of friction of the slide is 0.050, what is Linc's rate of acceleration as he slides down?

Solution: Start by constructing a triangle showing all the forces acting on the lifeguard. Then find the normal force acting on Linc when he is inclined at an angle to the horizontal. Because the normal force always acts perpendicular to the surface on which the object sits, find this force with the use of trigonometry.



$$\cos\theta = \frac{\text{adj}}{\text{hyp}} = \frac{F_N}{mg}$$

$$F_N = mg\cos\theta = (65.0\ \text{kg})(10.0\ \text{m/s}^2)\cos 35.0° = 532\ \text{N}$$

Now use this normal force to find the force of friction.

Given: $F_N = 532$ N
$\mu = 0.050$

Unknown: $F_f = ?$
Original equation: $F_f = \mu F_N$

Solve: $F_f = \mu F_N = (0.050)(532\ \text{N}) = 27\ \text{N}$

Next, return to the original triangle to find the downward component of the weight, which pulls Linc down the slide.

$$\sin\theta = \frac{\text{opp}}{\text{hyp}} = \frac{F_d}{mg}$$

$$F_d = mg\sin\theta = (65.0\ \text{kg})(10.0\ \text{m/s}^2)\sin 35.0° = 373\ \text{N}$$

The exercise asks for Linc's acceleration at the bottom of the slide. Because friction opposes Linc's motion, subtract its effect from F_d. The net force acting on Linc is

$$F_{net} = F_d - F_f = 373\ \text{N} - 27\ \text{N} = 346\ \text{N}$$

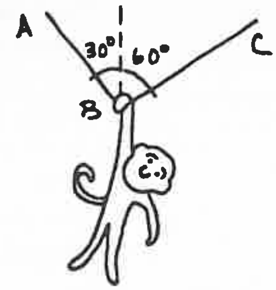
Now solve for the rate of acceleration.

Given: $F = 346$ N
$m = 65.0$ kg

Unknown: $a = ?$
Original equation: $F = ma$

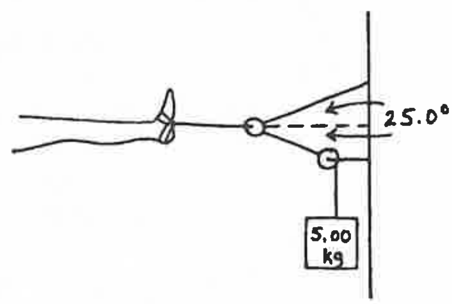
Solve: $a = \frac{F}{m} = \frac{346\ \text{N}}{65.0\ \text{kg}} = \mathbf{5.32\ m/s^2}$

B-1: Malcolm, the 20.0-kg monkey, hangs from a jungle vine, as shown. a) What is the tension in the segment of vine labeled AB? b) What is the tension in the segment of the vine labeled BC?



B-2: Noah is loading the ark and the last animal on board is a stubborn 1500-kg elephant who refuses to budge. Noah and his family pull the elephant at a constant speed up the 10° incline with a force of 10 000 N. What is the coefficient of sliding friction between the elephant and the loading platform?

B-3: Blythe lies in a hospital bed with her foot in traction, as shown. How much tension will the traction device exert on her foot?



B-4: Madison, whose mass is 35.0 kg, climbs the ladder on the slide in her back yard, and slides to the ground at an angle of 30.0° to the horizontal. If the coefficient of sliding friction is 0.15, what is Madison's acceleration down the slide? Ignore the initial effects of starting friction.

B-5: A chunk of rock of mass 50.0 kg slides down the side of a volcano that slopes up at an angle of 30.0° to the horizontal. If the rock accelerates at a rate of 3.0 m/s^2, what is the coefficient of sliding friction between the rock and the side of the volcano?

B-6: While waterskiing behind her father's boat, Cheryl is pulled at a constant speed with a force of 164 N by a rope that makes an angle of 10.0° with the horizontal. If Cheryl has a mass of 65.0 kg, what is the coefficient of sliding friction between Cheryl and the water?

B-7: Gooluk, the Inuit, is pulling a 62.0-kg sled through the snow on his way home from ice fishing. On the back of the sled is his 50.0-kg sack of fishing tackle. The coefficient of sliding friction between the sled and the snow is 0.0700 and the coefficient of sliding friction between the sled and the sack is 0.100. While pulling, the fishing rod sticking out of his sack catches on a tree branch, but Gooluk doesn't notice and keeps walking. What force does Gooluk need to exert to keep the sled moving with a constant speed while the sack is pulled back across it?