

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

$$\text{force} = (\text{mass})(\text{acceleration}) \quad \text{or} \quad F = ma$$

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** ($N = \text{kg} \cdot \text{m}/\text{s}^2$).

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 $10.0 \text{ m}/\text{s}^2$, the object will no longer have the same weight as it did on Earth. The equation for weight is just a specific case of $F = ma$.

$$\text{weight} = (\text{mass})(\text{acceleration due to gravity}) \quad \text{or} \quad w = mg$$

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

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

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

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: $m = 0.02 \text{ kg}$
 $F = -2.0 \text{ N}$

Unknown: $a = ?$

Original equation: $F = ma$

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

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.

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



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

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

Unknown: $a = ?$

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

$$\begin{aligned} \text{Solve: } a &= \frac{v_f^2 - v_o^2}{2\Delta d} = \frac{(25.0 \text{ m/s})^2 - (30.0 \text{ m/s})^2}{2(0.0800 \text{ m})} = \frac{625 \text{ m}^2/\text{s}^2 - 900. \text{ m}^2/\text{s}^2}{0.160 \text{ m}} \\ &= -1720 \text{ m/s}^2 \end{aligned}$$

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

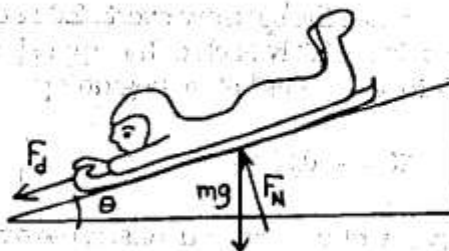
Unknown: $F = ?$

Original equation: $F = ma$

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

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.

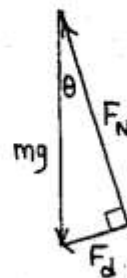
Example 5: Rose is sledding down an ice-covered hill inclined at an angle of 15° with the horizontal. If Rose and the sled have a combined mass of 54.0 kg , what is the force pulling them down the hill?



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

- First, there is the **gravitational force**, which always acts downward. This is the weight of the sled. It is labeled mg .
- 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 .
- 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: $m = 54.0\text{ kg}$
 $g = 10.0\text{ m/s}^2$
 $\theta = 15^\circ$

Unknown: $F_d = ?$

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

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

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 $3.0 \times 10^4 \text{ m/s}^2$. 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: _____