Newton's Laws of Motion 2.2

You are riding on a roller coaster with the safety harness snugly over your shoulders. Suddenly, an applied force causes the coaster to accelerate forward and you feel the back of the seat pressing hard against you. When the ride nears its end and a braking force causes the coaster to come to a quick stop, you feel as if you are being pressed forward against the harness. In this section, we will explore the origins of the forces that you experience on a roller coaster ride and those in other everyday situations.

The study of forces and the effects they have on the velocities of objects is called **dynamics**, from the Greek word *dynamis*, which means power. Three important principles related to dynamics are attributed to Sir Isaac Newton (**Figure 1**) and are called Newton's laws of motion.

dynamics the study of forces and the effects they have on motion

Newton's First Law of Motion

Picture a briefcase resting horizontally on the overhead shelf of a commuter train travelling at a constant velocity. As the train starts to slow down, you notice that the briefcase slides forward (relative to the train). What is happening?

It is instructive to learn how scientists analyzed this type of motion in the past. In ancient times, people who studied dynamics believed that an object moves with a constant velocity only when a constant external net force is applied. When Renaissance scientists, such as Galileo, began experimenting with dynamics, they verified that an object maintains a constant velocity when the net force acting on it is zero. **Figure 2** shows an example of each of these two points of view.

Figure 1
Isaac Newton, born in 1642, was perhaps the greatest of all mathematical physicists. In 1687, he published the book *Mathematical Principles of Natural Philosophy*, usually referred to as the *Principia*. In it, he described the works of other scientists as well as his own studies, including what are now called his three laws of motion and the law of universal gravitation. The concepts presented in his book represent a great leap forward in the world's understanding of the past, present, and future of the universe. Newton also contributed greatly to the studies of light, optics, and calculus. Although he died in 1727 at the age of 85, most of his great ideas were formulated by the age of 25.

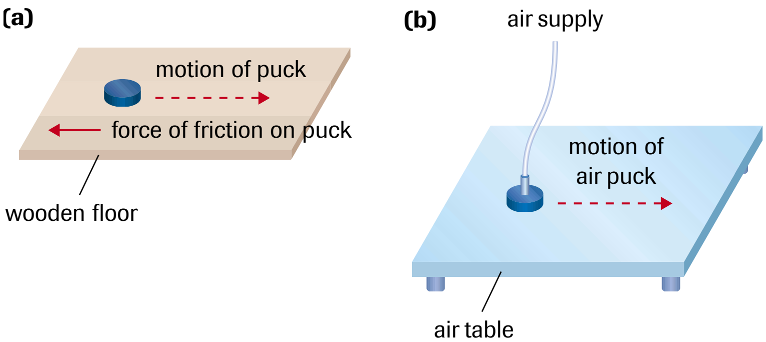


Figure 2
(a) A puck sliding along the floor soon comes to rest. Scientists prior to Galileo believed that an object needed a net force to maintain constant velocity. We now know that the only net force acting on the puck in this case is friction.
(b) An air-hockey puck that slides along a surface with negligible friction maintains a constant velocity. This verifies Galileo's view that an object moving with constant velocity keeps moving at that velocity if the net force is zero.

Newton summarized Galileo's ideas about objects at rest and objects moving with constant velocity in his *first law of motion*.

Newton's First Law of Motion

If the net force acting on an object is zero, that object maintains its state of rest or constant velocity.

LEARNING TIP

The Concept of Inertia

A helpful way to think about inertia is in terms of the object's mass. Inertia is directly related to an object's mass: the greater the mass, the greater the inertia. For example, a sports car has a small inertia compared to a train. Thus, the car requires a much smaller net force than the train to cause it to accelerate from rest to a speed of 100 km/h. When the car and the train are travelling at the same speed, the train has a much larger inertia than the car.

inertia the property of matter that causes an object to resist changes to its motion

This law has important implications. An external net force is required to change an object's velocity; internal forces have no effect on an object's motion. For example, pushing on the dashboard of a car does not change the car's velocity. To cause a change in velocity—in other words, to cause acceleration—the net force acting on an object cannot be zero.

A common way to interpret this law is to say that an object at rest or moving with a constant velocity tends to maintain its state of rest or constant velocity unless acted upon by an external net force. The ability of an object to resist changes to its motion is a fundamental property of all matter called *inertia*. **Inertia** tends to keep a stationary object at rest or a moving object in motion in a straight line at a constant speed. Thus, the first law of motion is often called the *law of inertia*.

Examples of the law of inertia are common in everyday life. If you are standing on a stationary bus and it starts to accelerate forward, you tend to stay where you are initially, which means that you will start to fall backward relative to the accelerating bus. **Figure 3** shows another example of inertia.

Consider the inertia of an object in motion. One example is the briefcase on the overhead shelf in the commuter train. Another example occurs when a car slows down quickly; the people in the car tend to continue moving forward, possibly crashing their heads into the windshield if they are not wearing a seat belt. Wearing a seat belt properly helps to reduce the serious injuries that can occur in this situation. A seat belt also helps prevent injuries that can occur when an airbag deploys in a front-end collision. The operation of one type of seat belt is shown in **Figure 4**.

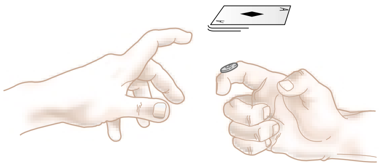


Figure 3
If a coin is balanced on a horizontal playing card on a finger and the card is flicked away, the coin, because of its inertia, will remain at rest on the finger.

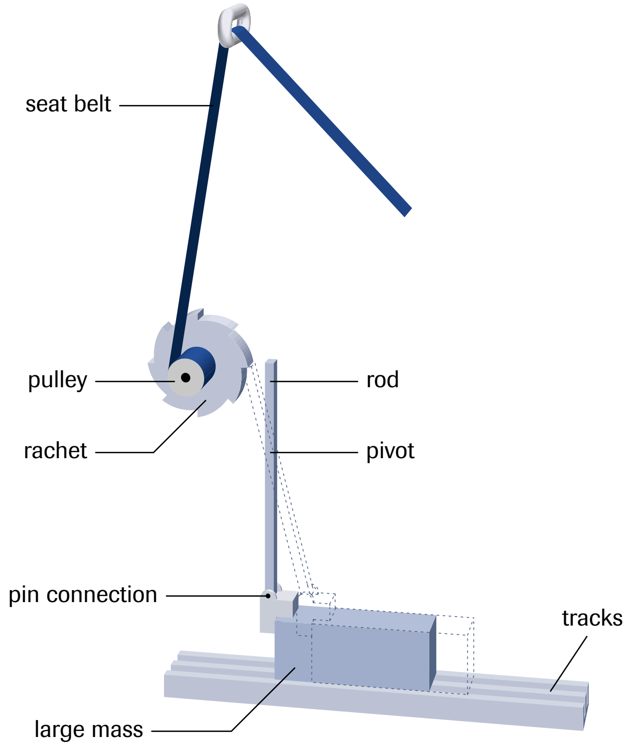


Figure 4
The operation of the seat belt shown here relies on the principle of inertia. Normally the ratchet turns freely, allowing the seat belt to wind or unwind whenever the passenger moves. With the car moving forward (to the right in this diagram), then slowing abruptly, the large mass on the track continues to move forward because of inertia. This causes the rod to turn on its pivot, locking the ratchet wheel and keeping the belt firmly in place.

SAMPLE problem 1

A 12-passenger jet aircraft of mass 1.6×10^4 kg is travelling at constant velocity of 850 km/h [E] while maintaining a constant altitude. What is the net force acting on the aircraft?

Solution

According to Newton's first law, the net force on the aircraft must be zero because it is moving with a constant velocity. **Figure 5** is an FBD of the aircraft. The vector sum of all the forces is zero.

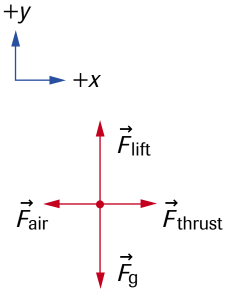


Figure 5
The FBD of the aircraft in Sample Problem 1

SAMPLE problem 2

You exert a force of 45 N [up] on your backpack, causing it to move upward with a constant velocity. Determine the force of gravity on the pack.

Solution

The FBD of the pack (**Figure 6**) shows that two forces act on the pack: the applied force ($\vec{F}_{app}$) that you exert and the force of gravity ($\vec{F}_g$) that Earth exerts. Since the pack is moving at a constant velocity, the net force must, by the law of inertia, be zero. So the upward and downward forces have the same magnitude, and $\vec{F}_g = 45$ N [down].

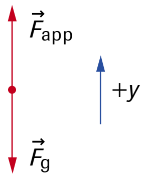


Figure 6
The FBD of the backpack in Sample Problem 2

Any object that has zero net force acting on it is in a state of equilibrium. In this sense, **equilibrium** is the property of an object experiencing no acceleration. The object can be at rest (static equilibrium) or moving at a constant velocity (dynamic equilibrium). In analyzing the forces on objects in equilibrium, it is convenient to consider the components of the force vectors. In other words, the condition for equilibrium, $\Sigma\vec{F} = 0$, can be written as $\Sigma F_x = 0$ and $\Sigma F_y = 0$.

equilibrium property of an object experiencing no acceleration

SAMPLE problem 3

The traction system of **Figure 7** stabilizes a broken tibia. Determine the force of the tibia on the pulley. Neglect friction.

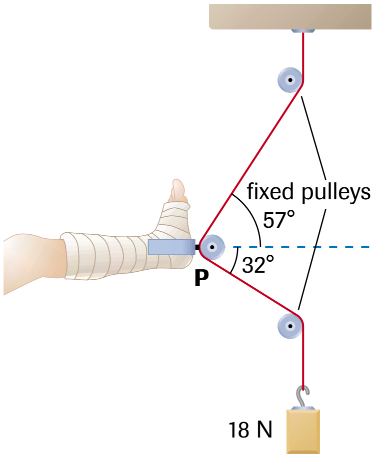


Figure 7
The system diagram of a leg in traction for Sample Problem 3

Solution

The FBD of the pulley (P) is shown in **Figure 8**. Since there is only one cord, we know there must be only one tension, which is 18 N throughout the cord. The net force on the pulley consists of both the horizontal (x) and vertical (y) components. We will use $\vec{F}_{tibia}$ as the symbol for the force of the tibia on the pulley.

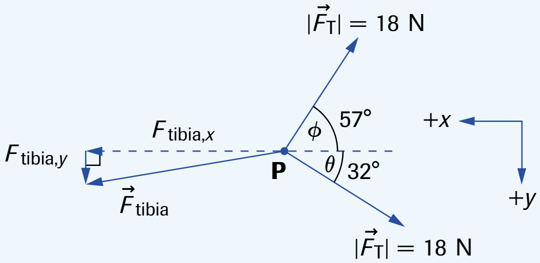


Figure 8
The FBD of the pulley (P)

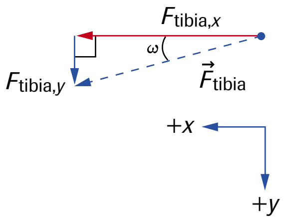


Figure 9
The force on the leg for Sample Problem 3

Horizontally:

$$
\begin{aligned}
\sum F_x &= 0 \\
F_{\text{tibia},x} - F_\text{T} \cos \phi - F_\text{T} \cos \theta &= 0 \\
F_{\text{tibia},x} &= F_\text{T} (\cos \phi + \cos \theta) \\
&= (18 \text{ N})(\cos 57° + \cos 32°) \\
F_{\text{tibia},x} &= 25 \text{ N}
\end{aligned}
$$

Vertically:

$$
\begin{aligned}
\sum F_y &= 0 \\
F_{\text{tibia},y} - F_\text{T} \sin \phi + F_\text{T} \sin \theta &= 0 \\
F_{\text{tibia},y} &= F_\text{T} (\sin \phi - \sin \theta) \\
&= (18 \text{ N})(\sin 57° - \sin 32°) \\
F_{\text{tibia},y} &= 5.6 \text{ N}
\end{aligned}
$$

From **Figure 9**, we can calculate the magnitude of the force:

$$
\begin{aligned}
|\vec{F}_{\text{tibia}}| &= \sqrt{(25 \text{ N})^2 + (5.6 \text{ N})^2} \\
|\vec{F}_{\text{tibia}}| &= 26 \text{ N}
\end{aligned}
$$

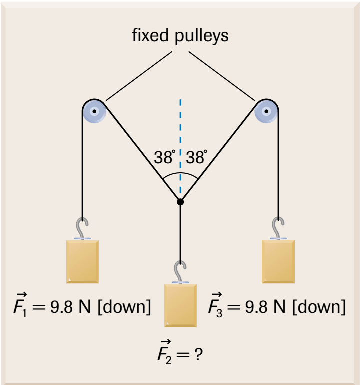
We now determine the angle:

$$
\begin{aligned}
\omega &= \tan^{-1} \frac{F_{\text{tibia},y}}{F_{\text{tibia},x}} \\
&= \tan^{-1} \frac{5.6 \text{ N}}{25 \text{ N}} \\
\omega &= 13°
\end{aligned}
$$

The force of the tibia on the pulley is 26 N [13° below the horizontal].

ACTIVITY 2.2.1

Static Equilibrium of Forces (p. 112)



The above diagram shows a possible setup for a vertical force board. (You may prefer to modify the setup, however, using a force table instead of a force board, as suggested for this activity.) In this vertical force board, there are three different forces, each acting on a different string. If two of the forces are known, the third force can be determined. Describe how you would determine the unknown force $\vec{F}_2$.

In Activity 2.2.1, in the Lab Activities section at the end of this chapter, you will predict the force or forces needed for static equilibrium in a specific situation and check your predictions experimentally. Various methods can be used to accomplish this, including using a force table or a force board.

Practice

Understanding Concepts

1. Assume the 8-passenger Learjet shown in **Figure 10** has a force of gravity of 6.6×10^4 N [down] acting on it as it travels at a constant velocity of 6.4×10^2 km/h [W]. If the forward thrust provided by the engines is 1.3×10^4 N [W], determine
   (a) the upward lift force on the plane
   (b) the force due to air resistance on the plane
2. Choose which of the objects in *italics* are not examples of Newton's first law, giving a reason in each case:
   (a) A cat-food *can* moves at a constant velocity on a conveyor belt in a factory.
   (b) A *skydiver* falls vertically at terminal speed.
   (c) A rubber *stopper* is tied to the end of a string and swings back and forth as a pendulum.
   (d) A *shopper* stands on an escalator, halfway between floors in a department store, and rises at a constant speed.
   (e) A *ball* travels with projectile motion after leaving a pitcher's hand.

3. A child is trying to push a large desk across a wooden floor. The child is exerting a horizontal force of magnitude 38 N, but the desk is not moving. What is the magnitude of the force of friction acting on the desk?
4. A snowboarder is travelling at a high speed down a smooth snow-covered hill. The board suddenly reaches a rough patch, encountering significant friction. Use Newton's first law to describe and explain what is likely to happen to the snowboarder.
5. You are sitting on a bus that is travelling at a constant velocity of 55 km/h [N]. You toss a tennis ball straight upward and it reaches a height just above the level of your eyes. Will the ball collide with you? Explain your answer.
6. The following sets of forces are acting on a common point. Determine the additional force needed to maintain static equilibrium.
   (a) 265 N [E]; 122 N [W]
   (b) 32 N [N]; 44 N [E]
   (c) 6.5 N [25° E of N]; 4.5 N [W]; 3.9 N [15° N of E]
7. A single clothesline is attached to two poles 10.0 m apart. A pulley holding a mass $\left(|\vec{F}_g| = 294 \text{ N}\right)$ rolls to the middle of the line and comes to rest there. The middle of the line is 0.40 m below each end. Determine the magnitude of the tension in the clothesline.

Applying Inquiry Skills

8. (a) Describe how you could use a piece of paper, a coin, and your desk to demonstrate the law of inertia for an object initially at rest.
   (b) Describe how you could safely demonstrate, using objects of your choosing, the law of inertia for an object initially in motion.

Making Connections

9. Explain the danger of stowing heavy objects in the rear window space of a car.

Answers

6. (a) 143 N [W]
   (b) 54 N [36° S of W]
   (c) 7.2 N [16° W of S]
7. 1.8×10^3 N

Figure 10
The Bombardier Learjet® 45, built by the Canadian firm Bombardier Inc., is one of the first executive jets designed entirely on computer.

Newton's Second Law of Motion

Speculate on how the magnitudes of the accelerations compare in each of the following cases:

- You apply an equal net force to each of two boxes initially at rest on a horizontal set of low-friction rollers. One box has a mass that is double the mass of the other box.
- Two identical boxes with the same mass are initially at rest on a horizontal set of low-friction rollers. You apply a net force to one box that is twice as large in magnitude as the force you apply to the other box.

In the first case, it is the less massive box that experiences the larger acceleration. In the second case, it is the box to which the greater force is applied that experiences the larger acceleration. It is obvious that an object's acceleration depends on both the object's mass and the net force applied.

To show mathematically how the acceleration of an object depends on the net force and the object's mass, we can analyze the results of an ideal controlled experiment. (The experiment is "ideal" because the force of friction is so small that it can be neglected. This can be achieved, for instance, by using an air puck on an air table.) **Table 1** gives data from the experiment.

Table 1 Experimental Data

Mass (kg)	Net Force (N [fwd])	Average Acceleration (m/s^2 [fwd])
1.0	1.0	1.0
1.0	2.0	2.0
1.0	3.0	3.0
2.0	3.0	1.5
3.0	3.0	1.0

As you can see in **Table 1**, as the net force increases for a constant mass, the acceleration increases proportionally, and as the mass increases with a constant force, the acceleration decreases proportionally. This relationship is the basis for Newton's *second law of motion.*

Newton's Second Law of Motion

If the external net force on an object is not zero, the object accelerates in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the object's mass.

Newton's first law involves situations in which the net force acting on an object is zero, so that no acceleration occurs. His second law includes situations in which the net force is nonzero, so that acceleration occurs in the direction of the net force.

To write the second law in equation form, we begin with the proportionality statements stated in the law: $\vec{a} \propto \Sigma\vec{F}$ (with a constant mass) and $\vec{a} \propto \frac{1}{m}$ (with a constant net force). Combining these statements, we obtain

$$\vec{a} \propto \frac{\Sigma\vec{F}}{m}$$

Converting this to an equation requires a constant of proportionality, k. Thus,

$$\vec{a} = \frac{k\Sigma\vec{F}}{m}$$

If the appropriate units are chosen for the variables, then $k = 1$ and

$$\vec{a} = \frac{\Sigma\vec{F}}{m}$$

Or, equivalently,

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

For the components, the corresponding relationships are:

$$\Sigma F_x = ma_x \quad \text{and} \quad \Sigma F_y = ma_y$$

We can now define the SI unit of force. The newton (N) is the magnitude of the net force required to give a 1-kg object an acceleration of magnitude 1 m/s^2. By substituting into the equation $\Sigma\vec{F} = m\vec{a}$, we see that

$$1\ \text{N} = 1\ \text{kg}\left(\frac{\text{m}}{\text{s}^2}\right) \quad \text{or} \quad 1\ \text{N} = 1\ \text{kg·m/s}^2$$

DID YOU KNOW?

Limitations of the Second Law

Newton's second law applies to all macroscopic objects—cars, bikes, people, rockets, planets, etc. The analysis of the motion of and forces on macroscopic objects is called *Newtonian mechanics*. The second law, however, does not apply to atomic and subatomic particles, such as electrons and quarks, where speeds are extremely high or the frame of reference is accelerating. In this microscopic realm, a different mathematical analysis, called *quantum mechanics*, applies.

SAMPLE problem 4

The mass of a hot-air balloon, including the passengers, is 9.0×10^2 kg. The force of gravity on the balloon is 8.8×10^3 N [down]. The density of the air inside the balloon is adjusted by adjusting the heat output of the burner to give a buoyant force on the balloon of 9.9×10^3 N [up]. Determine the vertical acceleration of the balloon.

Solution

$m = 9.0 \times 10^2$ kg

$F_g = |\vec{F}_g| = 8.8 \times 10^3$ N

$F_{app} = |\vec{F}_{app}| = 9.9 \times 10^3$ N

$a_y = ?$

Figure 11 is an FBD of the balloon.

$$\begin{aligned}
\sum F_y &= ma_y \\
a_y &= \frac{\sum F_y}{m} \\
&= \frac{F_{\text{app}} - F_{\text{g}}}{m} \\
&= \frac{9.9 \times 10^3 \text{ N} - 8.8 \times 10^3 \text{ N}}{9.0 \times 10^2 \text{ kg}} \\
&= \frac{1.1 \times 10^3 \text{ kg}\cdot\text{m/s}^2}{9.0 \times 10^2 \text{ kg}} \\
a_y &= 1.2 \text{ m/s}^2
\end{aligned}$$

The acceleration of the balloon is 1.2 m/s^2 [up].

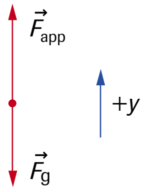


Figure 11
The FBD of the balloon shows the vertical forces as vectors. When only components are considered, the vector notation is omitted.

How does Newton's second law relate to his first law? According to the second law, $\vec{a} = \frac{\Sigma \vec{F}}{m}$, if the net force is zero, the acceleration must be zero, which implies that the velocity is constant (and could be zero). This agrees with the first law statement. It is evident that the first law is simply a special case of the second law, where $\Sigma \vec{F} = 0$.

Practice

Understanding Concepts

10. A horizontal force is applied to a hockey puck of mass 0.16 kg initially at rest on the ice. The resulting acceleration of the puck has a magnitude of 32 m/s^2. What is the magnitude of the force? Neglect friction.

11. A fire truck with a mass of 2.95×10^4 kg experiences a net force of 2.42×10^4 N [fwd]. Determine the acceleration of the truck.

12. Derive an equation for the constant net force acting on an object in terms of the object's mass, its initial velocity, its final velocity, and the time interval during which the net force is applied.

13. A 7.27-kg bowling ball, travelling at 5.78 m/s [W], strikes a lone pin straight on. The collision lasts for 1.2 ms and causes the ball's velocity to become 4.61 m/s [W] just after the collision. Determine the net force (assumed to be constant) on the ball during the collision.

Applying Inquiry Skills

14. Describe how you would use an elastic band, three small carts with low-friction wheels, and a smooth horizontal surface to safely demonstrate Newton's second law. (Your demonstration need not involve taking numerical data.) Obtain teacher approval if you wish to try your demonstration.

Making Connections

15. Mining operations in outer space will require unique innovations if they are carried out where there is a very low force of gravity, such as on asteroids or the moons of various planets. One plan is to develop a device that will push particles with the same constant force, separating them according to the accelerations they achieve. Research "mining methods in zero-*g*" to learn more about this application of Newton's second law. Describe what you discover.

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Answers

10. 5.1 N
11. 0.820 m/s^2 [fwd]
13. 7.1×10^3 N [E]

Weight and Earth's Gravitational Field

weight the force of gravity on an object

We can apply Newton's second law to understand the scientific meaning of weight. The **weight** of an object is equal to the force of gravity acting on an object. Notice that this definition is different from *mass*, which is the quantity of matter. From the second law:

$$\text{weight} = \vec{F}_g = m\vec{g}$$

For example, the weight of a 5.5-kg turkey is

$$\vec{F}_g = m\vec{g} = (5.5\text{ kg})(9.8\text{ N/kg [down]}) = 54\text{ N [down]}$$

force field space surrounding an object in which a force exists

gravitational field strength ($\vec{g}$) amount of force per unit mass

Near Earth, weight results from Earth's relatively large force of attraction on other bodies around it. The space surrounding an object in which a force exists is called a **force field**. The gravitational force field surrounding Earth extends from Earth's surface far into space. At Earth's surface, the amount of force per unit mass, called the **gravitational field strength**, is 9.8 N/kg [down] (to two significant digits). This value is a vector quantity directed toward Earth's centre and is given the symbol $\vec{g}$. Notice that the gravitational field strength has the same value as the average acceleration due to gravity at Earth's surface, although for convenience the units are written differently. The two values are interchangeable and they have the same symbol, $\vec{g}$.

Earth's gravitational field strength, and thus the weight of objects on Earth's surface, varies slightly depending on various factors, which will be explored in Unit 2.

Practice

Understanding Concepts

16. Determine, from the indicated masses, the magnitude of the weight (in newtons) for each of the following stationary objects on Earth's surface:
   (a) a horseshoe (2.4 kg)
   (b) an open-pit coal-mining machine (1.3 Gg)
   (c) a table tennis ball (2.50 g) (Assume $|\vec{g}| = 9.80$ N/kg.)
   (d) a speck of dust (1.81 μg) (Assume $|\vec{g}| = 9.80$ N/kg.)
   (e) you

17. Determine the mass of each of the following objects, assuming that the object is stationary in a gravitational field of 9.80 N/kg [down]:
   (a) a field hockey ball with a weight of 1.53 N [down]
   (b) cargo attaining the 1.16 MN [down] weight limit of a C-5 Galaxy cargo plane

18. What is the weight of a 76-kg astronaut on a planet where the gravitational field strength is 3.7 N/kg [down]?

Applying Inquiry Skills

19. Show that the units N/kg and m/s^2 are equivalent.

Answers

16. (a) 24 N
    (b) 1.3×10^7 N
    (c) 2.45×10^{-2} N
    (d) 1.77×10^{-8} N
17. (a) 1.56×10^{-1} kg
    (b) 1.18×10^5 kg
18. 2.8×10^2 N [down]

Newton's Third Law of Motion

When a balloon is inflated and released, air rushing from the open nozzle causes the balloon to fly off in the opposite direction (**Figure 12(a)**). Evidently, when the balloon exerts a force on the air in one direction, the air exerts a force on the balloon in the opposite direction. This is illustrated in **Figure 12(b)** where vertical forces are not shown because they are so small.

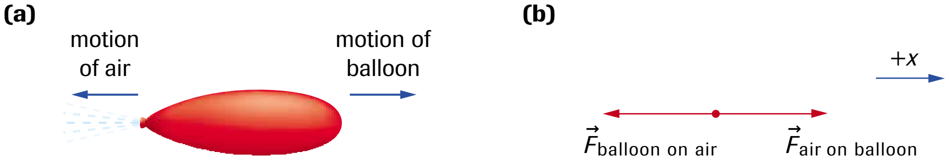

Figure 12
(a) When an inflated balloon is released, air bursts out in one direction and the balloon reacts in the opposite direction.
(b) Two simultaneous forces acting on different objects

This example brings us to Newton's *third law of motion*, commonly called the *action–reaction law*, which considers forces that act in pairs on two objects. Notice that this differs from the first and second laws where only one object at a time was considered.

> **Newton's Third Law of Motion**
> For every action force, there is a simultaneous reaction force equal in magnitude but opposite in direction.

The third law can be used to explain situations where a force is exerted on one object by a second object. To illustrate how this law applies to the motion of people and vehicles, consider the following examples, which are also illustrated in **Figure 13**.

- When a motorcycle accelerates forward, the tires exert a backward action force on the road and the road exerts a forward reaction force on the tires. These forces are static friction between the tires and the road.
- When you walk, your feet exert an action force downward and backward on the floor, while the floor exerts a reaction force upward and forward on your feet.
- When you row a boat, the oar exerts an action force backward on the water and the water exerts a reaction force forward on the oar attached to the boat.

LEARNING TIP

Naming Action–Reaction Pairs
In the examples of action-reactions pairs shown in **Figure 13**, one force is called the action force and the other is called the reaction force. These two forces act on different objects. Since both forces occur simultaneously, it does not matter which is called the action force and which is called the reaction force. The names can be interchanged with no effect on the description.

Figure 13
Illustrations of Newton's third law of motion
(a) A tire accelerates on a road.
(b) A foot moves on a floor.
(c) Oars propel a boat.

SAMPLE problem 5

A softball player sliding into third base experiences the force of friction. Describe the action-reaction pair of forces in this situation.

Solution

We arbitrarily designate the action force to be the force of the ground on the player (in a direction opposite to the player's sliding motion). Given this choice, the reaction force is the force exerted by the player on the ground (in the direction of the player's sliding motion).

Practice

Understanding Concepts

20. Explain the motion of each of the following objects in *italics* using the third law of motion. Describe the action and reaction forces, and their directions.
   (a) A *rocket* being used to put a communications satellite into orbit has just left the launch pad.
   (b) A rescue *helicopter* hovers above a stranded victim on a rooftop beside a flooded river.
   (c) An inflated *balloon* is released from your hand and travels eastward for a brief time interval.

21. You are holding a pencil horizontally in your hand.
   (a) Draw a system diagram of this situation, showing all the action-reaction pairs of forces associated with the pencil.
   (b) Explain, with the help of an FBD, why the pencil is not accelerating.

Applying Inquiry Skills

22. Describe how you would safely demonstrate Newton's third law to students in elementary school using toys.

SUMMARY Newton's Laws of Motion

- Dynamics is the study of forces and the effects the forces have on the velocities of objects.
- The three laws of motion and the SI unit of force are named after Sir Isaac Newton.
- Newton's first law of motion (also called the law of inertia) states: If the net force acting on an object is zero, the object maintains its state of rest or constant velocity.
- Inertia is the property of matter that tends to keep an object at rest or in motion.
- An object is in equilibrium if the net force acting on it is zero, which means the object is either at rest or is moving at a constant velocity.
- Newton's second law of motion states: If the external net force on an object is not zero, the object accelerates in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the object's mass. The second law can be written in equation form as $\vec{a} = \frac{\Sigma \vec{F}}{m}$ (equivalently, $\Sigma \vec{F} = m\vec{a}$).
- Both the first and second laws deal with a single object; the third law deals with two objects.
- The SI unit of force is the newton (N): $1\ \text{N} = 1\ \text{kg}\cdot\text{m/s}^2$.
- The weight of an object is the force of gravity acting on it in Earth's gravitational field. The magnitude of the gravitational field at Earth's surface is 9.8 N/kg, which is equivalent to 9.8 m/s^2.
- Newton's third law of motion (also called the action-reaction law) states: For every action force, there is a simultaneous force equal in magnitude, but opposite in direction.

Section 2.2 Questions

Understanding Concepts

1. A mallard duck of mass 2.3 kg is flying at a constant velocity of 29 m/s [15° below the horizontal]. What is the net force acting on the duck?

2. A 1.9-kg carton of juice is resting on a refrigerator shelf. Determine the normal force acting on the carton.

3. An electrical utility worker with a mass of 67 kg, standing in a cherry picker, is lowered at a constant velocity of 85 cm/s [down]. Determine the normal force exerted by the cherry picker on the worker.

4. Magnetic forces act on the electron beams in television tubes. If a magnetic force of magnitude 3.20×10^{-15} N is exerted on an electron ($m_e = 9.11 \times 10^{-31}$ kg), determine the magnitude of the resulting acceleration. (The mass of an electron is so low that gravitational forces are negligible.)

5. A karate expert shatters a brick with a bare hand. The expert has a mass of 65 kg, of which 0.65 kg is the mass of the hand. The velocity of the hand changes from 13 m/s [down] to zero in a time interval of 3.0 ms. The acceleration of the hand is constant.
(a) Determine the acceleration of the hand
(b) Determine the net force acting on the hand. What object exerts this force on the hand?
(c) Determine the ratio of the magnitude of the net force acting on the hand to the magnitude of the expert's weight.

6. In target archery, the magnitude of the maximum draw force applied by a particular bow is 1.24×10^2 N. If this force gives the arrow an acceleration of magnitude 4.43×10^3 m/s^2, what is the mass, in grams, of the arrow?

7. The magnitude of the gravitational field strength on Venus is 8.9 N/kg.
(a) Calculate the magnitude of your weight on the surface of Venus.
(b) By what percentage would the magnitude of your weight change if you moved to Venus?

8. One force is given for each of the following situations. Identify the other force in the action-reaction pair, and indicate the name of the force, its direction, the object that exerts it, and the object on which it is exerted:
(a) A chef exerts a force on a baking pan to pull it out of an oven.
(b) The Sun exerts a gravitational force on Saturn.
(c) A swimmer's hands exert a backward force on the water.
(d) Earth exerts a gravitational force on a watermelon.
(e) An upward force of air resistance is exerted on a falling hailstone.

9. Two identical bags of gumballs, each of mass 0.200 kg, are suspended as shown in **Figure 14**. Determine the reading on the spring scale.

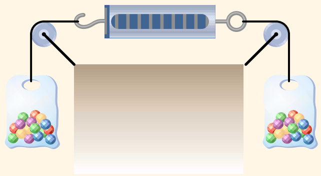

Figure 14

Applying Inquiry Skills

10. (a) Hold a calculator in your hand and estimate its mass in grams. Convert your estimate to kilograms.
(b) Determine the weight of the calculator from your mass estimate.
(c) Determine the weight of the calculator from its mass as measured on a balance.
(d) Determine the percent error in your estimate in (b).

Making Connections

11. An astronaut in the International Space Station obtains a measurement of personal body mass from an "inertial device," capable of exerting a measured force. The display on the device shows that a net force of 87 N [fwd] gives the astronaut an acceleration of 1.5 m/s^2 [fwd] from rest for 1.2 s.
(a) Why is the astronaut unable to measure personal body mass on an ordinary scale, such as a bathroom scale?
(b) What is the mass of the astronaut?
(c) How far did the astronaut move during the 1.2-s time interval?
(d) Research how an inertial device works. Write a brief description of what you discover.

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12. Research the career of Isaac Newton. Report on some of his major accomplishments as well as his eccentricities.