section 1

* Annotated *

Newton's Second Law

Reading Guide

What You'll Learn

- **Define** Newton's second law of motion.
- **Apply** Newton's second law of motion.
- **Describe** the three different types of friction.
- **Observe** the effects of air resistance on falling objects.

Why It's Important

Newton's second law explains how forces cause the motion of objects to change.

Review Vocabulary

net force: the combination of all forces acting on an object

New Vocabulary

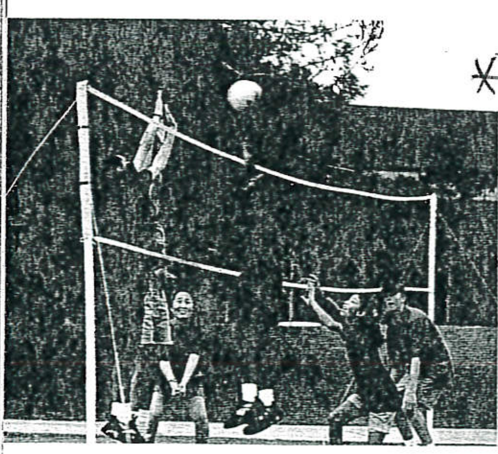
- Newton's second law of motion
- friction
- static friction
- sliding friction
- air resistance

Force, Mass, and Acceleration

The previous chapter discussed Newton's first law of motion which states that the motion of an object changes only if an unbalanced force acts on the object. Newton's second law of motion describes how the forces exerted on an object, like the volleyball in **Figure 1,** its mass, and its acceleration are related.

Force and Acceleration What's different about throwing a ball horizontally as hard as you can and tossing it gently? When you throw hard, you exert a much greater force on the ball. The ball has a greater velocity when it leaves your hand than it does when you throw gently. Thus, the hard-thrown ball has a greater change in velocity, and the change occurs over a shorter period of time. Recall that acceleration is the change in velocity divided by the time it takes for the change to occur. So, a hard-thrown ball has a greater acceleration than a gently thrown ball.

Figure 1 A volleyball's motion changes when an unbalanced force acts on it.



Mass and Acceleration If you throw a softball and a baseball as hard as you can, why don't they have the same speed? The difference is due to their masses. A softball has a mass of about 0.20 kg, but a baseball's mass is about 0.14 kg. The softball has less velocity after it leaves your hand than the baseball does, even though you exerted the same force. If it takes the same amount of time to throw both balls, the softball would have less acceleration. The acceleration of an object depends on its mass as well as the force exerted on it. Force, mass, and acceleration are related.

Newton's Second Law

Newton's second law of motion states that the acceleration of an object is in the same direction as the net force on the object, and that the acceleration can be calculated from the following equation:

F = m × a

Newton's Second Law of Motion

$$\text{acceleration (in meters/second}^2) = \frac{\text{net force (in newtons)}}{\text{mass (in kilograms)}}$$

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

Science Online

Topic: Motion in Sports

Visit gpscience.com for Web links to information about methods used to analyze the motions of athletes.

Activity Choose a sport and write a report on how analyzing the motions involved in the sport can improve performance and reduce injuries.

Applying Math — Solve a Simple Equation

THE ACCELERATION OF A SLED You push a friend on a sled. Your friend and the sled together have a mass of 70 kg. If the net force on the sled is 35 N, what is the sled's acceleration?

Units = Newtons

IDENTIFY known values and the unknown value

Identify the known values:

The net force on the sled is 35 N → means → $F_{net} = 35$ N

Your friend and the sled together have a mass of 70 kg → means → $m = 70$ kg

Identify the unknown value:

What is the sled's acceleration? → means → $a = ?$ m/s^2

SOLVE the problem

Substitute the known values $F_{net} = 35$ N and $m = 70$ kg into the equation for Newton's second law of motion:

$$a = \frac{F_{net}}{m} = \frac{35 \text{ N}}{70 \text{ kg}} = 0.5\,\frac{\text{N}}{\text{kg}} = 0.5\,\frac{\cancel{\text{kg}}\,\text{m}}{\text{s}^2} \times \frac{1}{\cancel{\text{kg}}} = 0.5 \text{ m/s}^2$$

CHECK the answer

Does your answer seem reasonable? Check your answer by multiplying the acceleration you calculated by the mass given in the problem. The result should be the net force given in the problem.

Practice Problems

1. If the mass of a helicopter is 4,500 kg, and the net force on it is 18,000 N, what is the helicopter's acceleration?
2. What is the net force on a dragster with a mass of 900 kg if its acceleration is 32.0 m/s^2?
3. A car is being pulled by a tow truck. What is the car's mass if the net force on the car is 3,000 N and it has an acceleration of 2.0 m/s^2?

For more practice problems go to page 834, and visit gpscience.com/extra_problems.

Figure 2 The tennis racket exerts a force on the ball that causes it to accelerate.

Calculating Net Force with the Second Law Newton's second law also can be used to calculate the net force if mass and acceleration are known. To do this, the equation for Newton's second law must be solved for the net force, F. To solve for the net force, multiply both sides of the above equation by the mass:

$$\cancel{m} \times \frac{F_{net}}{\cancel{m}} = ma$$

The mass, m, on the left side cancels, giving the equation:

$$F_{net} = ma$$

For example, when the tennis player in **Figure 2** hits a ball, the ball might be in contact with the racket for only a few thousandths of a second. Because the ball's velocity changes over such a short period of time, the ball's acceleration could be as high as 5,000 m/s^2. The ball's mass is 0.06 kg, so the net force exerted on the ball would be:

$$F_{net} = ma = (0.06 \text{ kg})\ (5{,}000 \text{ m/s}^2) = 300 \text{ kg m/s}^2 = 300 \text{ N}$$

Friction

Suppose you give a skateboard a push with your hand. According to Newton's first law of motion, if the net force acting on a moving object is zero, it will continue to move in a straight line with constant speed. Does the skateboard keep moving with constant speed after it leaves your hand?

You know the answer. The skate board slows down and finally stops. Recall that when an object slows down it is accelerating. By Newton's second law, if the skateboard is accelerating, there must be a net force acting on it.

The force that slows the skateboard and brings it to a stop is friction. **Friction** is the force that opposes the sliding motion of two surfaces that are touching each other. The amount of friction between two surfaces depends on two factors—the kinds of surfaces and the force pressing the surfaces together.

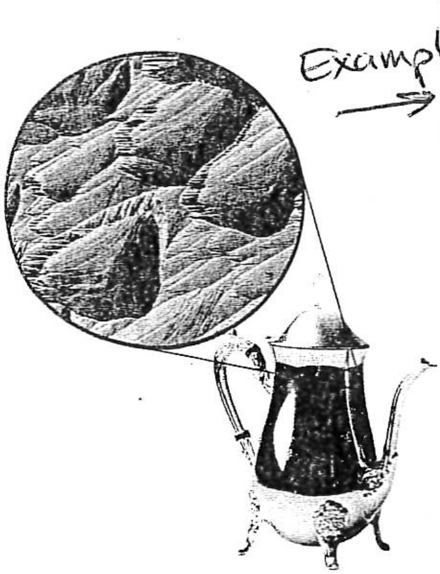


Figure 3 While surfaces might look and even feel smooth, they can be rough at the microscopic level.

Reading Check *What does the force of friction between two objects in contact depend on?*

What causes friction? Would you believe the surface of a highly polished piece of metal is rough? **Figure 3** shows a microscopic view of the dips and bumps on the surface of a polished silver teapot. If two surfaces are in contact, welding or sticking occurs where the bumps touch each other. These microwelds are the source of friction.

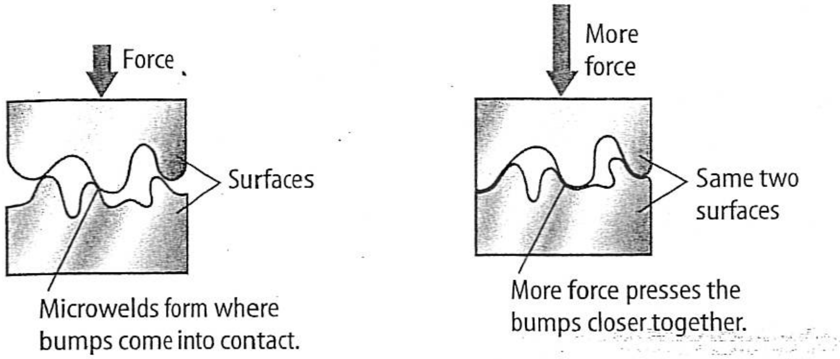


Figure 4 Friction is due to microwelds formed between two surfaces. The larger the force pushing the two surfaces together is, the stronger the microwelds will be.
Explain *how the area of contact between the surfaces changes when they are pushed together.*

Sticking Together The larger the force pushing the two surfaces together is, the stronger these microwelds will be, because more of the surface bumps will come into contact, as shown in **Figure 4.** To move one surface over the other, a force must be applied to break the microwelds.

Static Friction Suppose you have filled a cardboard box, like the one in **Figure 5,** with books and want to move it. It's too heavy to lift, so you start pushing on it, but it doesn't budge. Is that because the mass of the box is too large? If the box doesn't move, then it has zero acceleration. According to Newton's second law, if the acceleration is zero, then the net force on the box is zero. Another force that cancels your push must be acting on the box. That force is friction due to the microwelds that have formed between the bottom of the box and the floor. This type of friction is called static friction. **Static friction** is the frictional force that prevents two surfaces from sliding past each other. In this case, your push is not large enough to break the microwelds, and the box does not move.

Mini LAB

Comparing Friction

Procedure

1. Place an **ice cube,** a **rock,** an **eraser,** a **wood block,** and a square of **aluminum foil** at one end of a **metal** or **plastic tray.**
2. Slowly lift the end of the tray with the items.
3. Have a partner use a **metric ruler** to measure the height of the raised end of the tray at which each object slides to the other end. Record the heights in your **Science Journal.**

Analysis

1. List the height at which each object slid off the tray.
2. Why did the objects slide off at different heights?
3. What type of friction acted on each object?

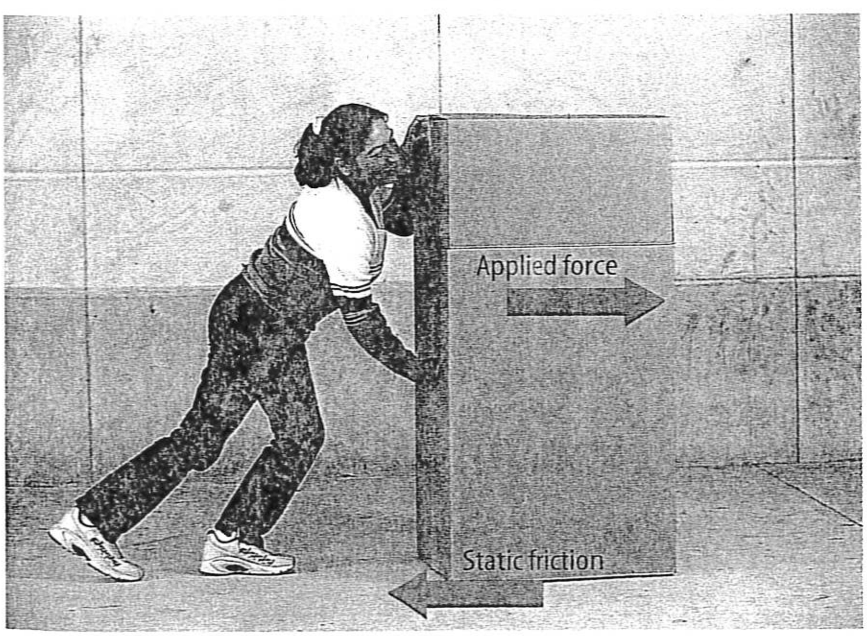


Figure 5 The box doesn't move because static friction is equal to the applied force.
Infer *the net force on the box.*

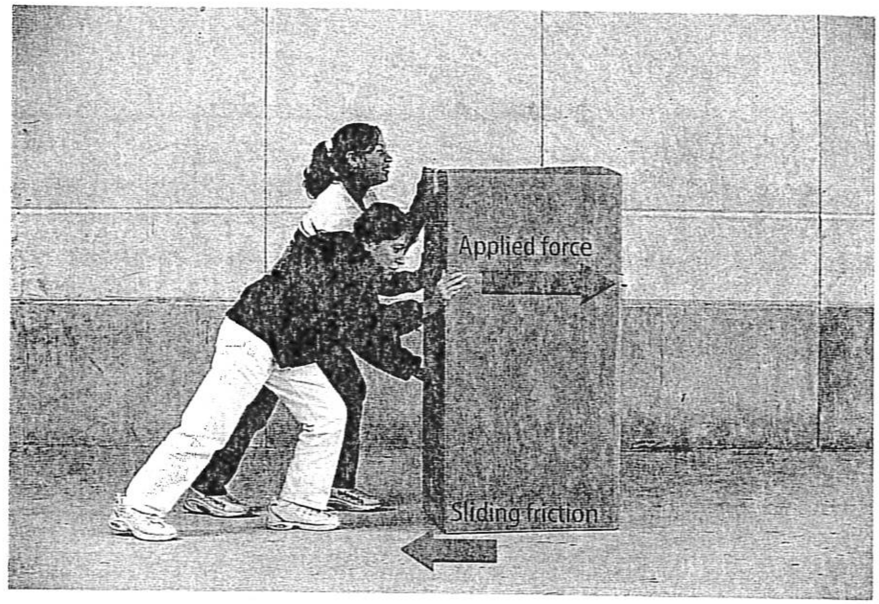


Figure 6 Sliding friction acts in the direction opposite the motion of the sliding box.

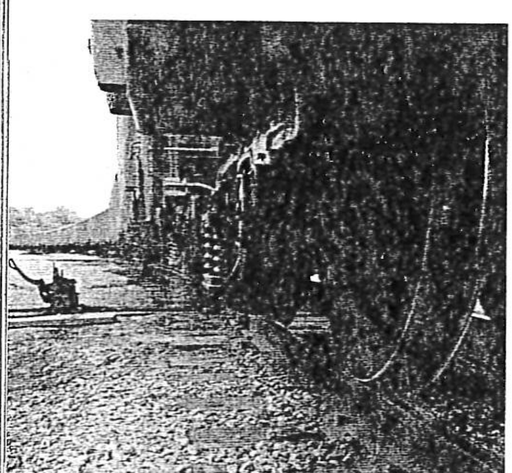
Sliding Friction You ask a friend to help you move the box, as in **Figure 6.** Pushing together, the box moves. Together you and your friend have exerted enough force to break the microwelds between the floor and the bottom of the box. But if you stop pushing, the box quickly comes to a stop. This is because as the box slides across the floor, another force—sliding friction—opposes the motion of the box. **Sliding friction** is the force that opposes the motion of two surfaces sliding past each other. Sliding friction is caused by microwelds constantly breaking and then forming again as the box slides along the floor. To keep the box moving, you must continually apply a force to overcome sliding friction.

Reading Check *What causes sliding friction?*

Rolling Friction You may have watched a car stuck in snow, ice, or mud spin its wheels. The driver steps on the gas, but the wheels just spin without the car moving. To make the car move, sand or gravel may be spread under the wheels. When a wheel is spinning there is sliding friction between the wheels and surface. Spreading sand or gravel on the surface increases the sliding friction until the wheel stops slipping and begins rolling.

As a wheel rolls over a surface, the wheel digs into the surface, causing both the wheel and the surface to be deformed. Static friction acts over the deformed area where the wheel and surface are in contact, producing a frictional force called rolling friction. Rolling friction is the frictional force between a rolling object and the surface it rolls on. Rolling friction would cause the train in **Figure 7** to slow down and come to a stop, just as sliding friction causes a sliding object to slow down and come to a stop.

Figure 7 Rolling friction between the train's wheels and the track is reduced by making both from steel. This reduces the deformation that occurs as the wheel rolls on the track.



Air Resistance

When an object falls toward Earth, it is pulled downward by the force of gravity. However, a friction-like force called **air resistance** opposes the motion of objects that move through the air. Air resistance causes objects to fall with different accelerations and different speeds. If there were no air resistance, then all objects, like the apple and the feather shown in **Figure 8,** would fall with the same acceleration.

Air resistance acts in the opposite direction to the motion of an object through air. If the object is falling downward, air resistance acts upward on the object. The size of the air resistance force also depends on the size and shape of an object. Imaging dropping two identical plastic bags. One is crumpled into a ball and the other is spread out. When the bags are dropped, the crumbled bag falls faster than the spread out-bag. The downward force of gravity on both bags is the same, but the upward force of air resistance on the crumpled bag is less. As a result, the net downward force on the crumpled bag is greater, as shown in **Figure 9.**

The amount of air resistance on an object depends on the speed, size, and shape of the object. Air resistance, not the object's mass, is why feathers, leaves, and pieces of paper fall more slowly than pennies, acorns, and apples.

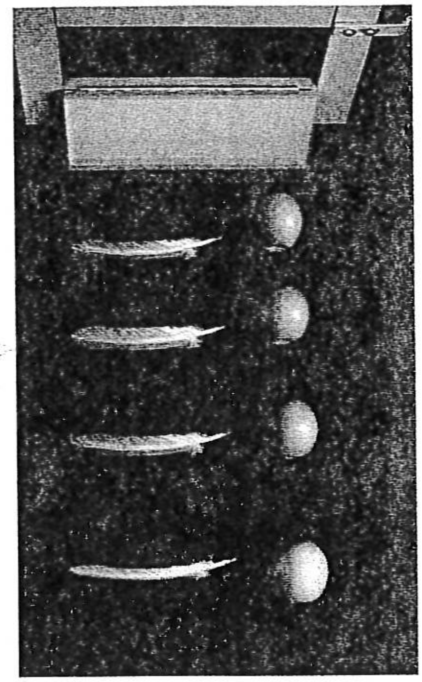


Figure 8 This photograph shows an apple and feather falling in a vacuum. The photograph was taken using a strobe light that flashes on and off at a steady rate. Because there is no air resistance in a vacuum, the feather and the apple fall with the same acceleration.

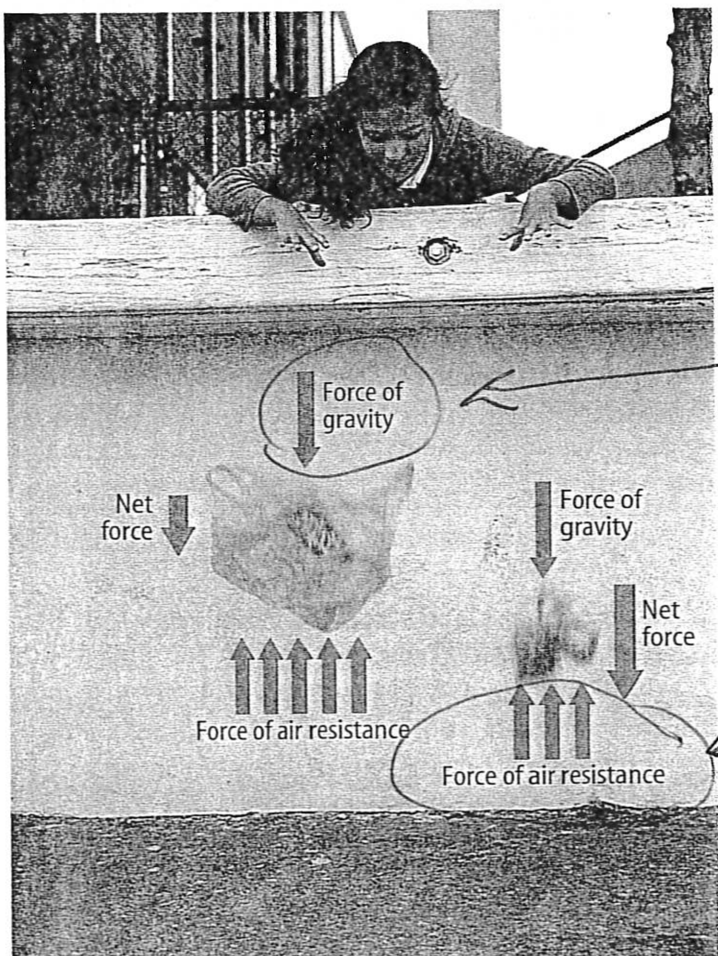


Figure 9 Because of its greater surface area, the bag on the left has more air resistance acting on it as it falls.

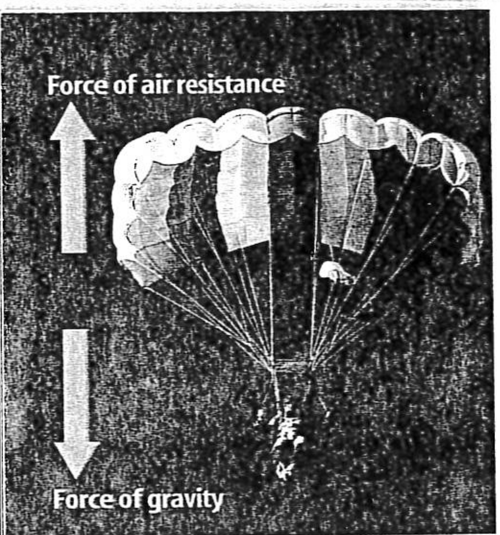


Figure 10 The force of air resistance on an open parachute balances the force of gravity on the sky diver when the parachute is falling slowly.

Terminal Velocity As an object falls, the downward force of gravity causes the object to accelerate. For example, after falling 2,000 m, without the effects of air resistance the sky diver's speed would be almost 200 m/s, or over 700 km/h.

However, as an object falls faster, the upward force of air resistance increases. This causes the net force on a sky diver to decrease as the sky diver falls. Finally, the upward air resistance force becomes large enough to balance the downward force of gravity. This means the net force on the object is zero. Then the acceleration of the object is also zero, and the object falls with a constant speed called the terminal velocity. The terminal velocity is the highest speed a falling object will reach.

The terminal velocity depends on the size, shape, and mass of a falling object. The air resistance force on an open parachute, like the one in **Figure 10,** is much larger than the air resistance on the sky diver with a closed parachute. With the parachute open, the terminal velocity of the sky diver becomes small enough that the sky diver can land safely.

section 1 review

Summary

Force, Mass, and Acceleration

- The greater the force on an object, the greater the object's acceleration.
- The acceleration of an object depends on its mass as well as the force exerted on it.

Newton's Second Law

- Newton's second law of motion states that the acceleration of an object is in the direction of the net force on the object, and can be calculated from this equation:

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Friction

- Friction is the force that opposes motion between two surfaces that are touching each other.
- Friction depends on the types of surfaces and the force pressing the surfaces together.
- Friction results from the microwelds formed between surfaces that are in contact.

Air Resistance

- Air resistance is a force that acts on objects that move through the air.

Self Check

1. **State** Newton's second law of motion.
2. **Infer** why an object with a smaller mass has a larger acceleration than a larger mass if the same force acts on each.
3. **Explain** why the frictional force between two surfaces increases if the force pushing the surfaces together increases.
4. **Compare** the force of air resistance and the force of gravity on an object falling at its terminal velocity.
5. **Think Critically** Why does coating surfaces with oil reduce friction between the surfaces?

Applying Math

6. **Convert Units** show that the units N/kg can be written using only units of meters (m) and seconds (s). Is this a unit of mass, acceleration or force?
7. **Calculate Mass** You push yourself on a skateboard with a force of 30 N and accelerate at 0.5 m/s^2. Find the mass of the skateboard if your mass is 58 kg.
8. **Calculate Sliding Friction** You push a 2-kg book with a force of 5 N. Find the force of sliding friction on the book if it has an acceleration of 1.0 m/s^2.

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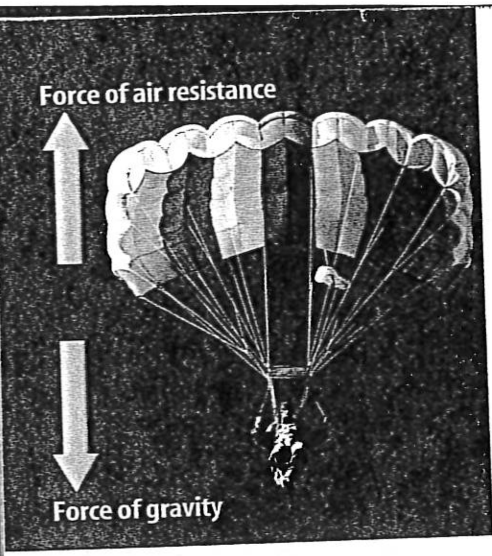

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