4.2 Newton's First Law of Motion: Inertia

Section Learning Objectives

By the end of this section, you will be able to do the following:

- Describe Newton's first law and friction, and
- Discuss the relationship between mass and inertia.

Teacher Support

Teacher Support The learning objectives in this section will help students master the following standards:

- (4) Science concepts. The student knows and applies the laws governing motion in a variety of situations. The student is expected to:
  - (D) calculate the effect of forces on objects, including the law of inertia, the relationship between force and acceleration, and the nature of force pairs between objects.

Before students begin this section, it is useful to review the concepts of force, external force, net external force, and addition of forces.

[BL][OL][AL] Ask students to speculate what happens to objects when they are set in motion. Do they remain in motion or stop after some time? Why?

Misconception Alert

Students may believe that objects that are in motion tend to slow down and stop. Explain the concept of friction. Talk about objects in outer space, where there is no atmosphere and no gravity. Ask students to describe the motion of such objects.

Section Key Terms

Newton's First Law and Friction

Teacher Support

Teacher Support [BL][OL][AL] Discuss examples of Newton's first law seen in everyday life.

[BL][OL][AL] Talk about different pairs of surfaces and how each exhibits different levels of friction. Ask students to give examples of smooth and rough surfaces. Ask them where friction may be useful and where it may be undesirable.

[OL][AL] Ask students to give different examples of systems where multiple forces occur. Draw free-body diagrams for these. Include the force of friction. Emphasize the direction of the force of friction.

Newton's first law of motion states the following:

1. A body at rest tends to remain at rest.
2. A body in motion tends to remain in motion at a constant velocity unless acted on by a net external force. (Recall that *constant velocity* means that the body moves in a straight line and at a constant speed.)

At first glance, this law may seem to contradict your everyday experience. You have probably noticed that a moving object will usually slow down and stop unless some effort is made to keep it moving. The key to understanding why, for example, a sliding box slows down (seemingly on its own) is to first understand that a net external force acts on the box to make the box slow down. Without this net external force, the box would continue to slide at a constant velocity (as stated in Newton's first law of motion). What force acts on the box to slow it down? This force is called friction. Friction is an external force that acts opposite to the direction of motion (see Figure 4.3). Think of friction as a resistance to motion that slows things down.

Consider an air hockey table. When the air is turned off, the puck slides only a short distance before friction slows it to a stop. However, when the air is turned on, it lifts the puck slightly, so the puck experiences very little friction as it moves over the surface. With friction almost eliminated, the puck glides along with very little change in speed. On a frictionless surface, the puck would experience no net external force (ignoring air resistance, which is also a form of friction). Additionally, if we know enough about friction, we can accurately predict how quickly objects will slow down.

Now let's think about another example. A man pushes a box across a floor at constant velocity by applying a force of
+50 N. (The positive sign indicates that, by convention, the direction of motion is to the right.) What is the force of friction that opposes the motion? The force of friction must be −50 N. Why? According to Newton's first law of motion, any object moving at constant velocity has no net external force acting upon it, which means that the sum of the forces acting on the object must be zero. The mathematical way to say that no net external force acts on an object is $\mathbf{F}_{\text{net}} = 0$ or $\Sigma\mathbf{F} = 0$. So if the man applies +50 N of force, then the force of friction must be −50 N for the two forces to add up to zero (that is, for the two forces to *cancel* each other). Whenever you encounter the phrase *at constant velocity*, Newton's first law tells you that the net external force is zero.

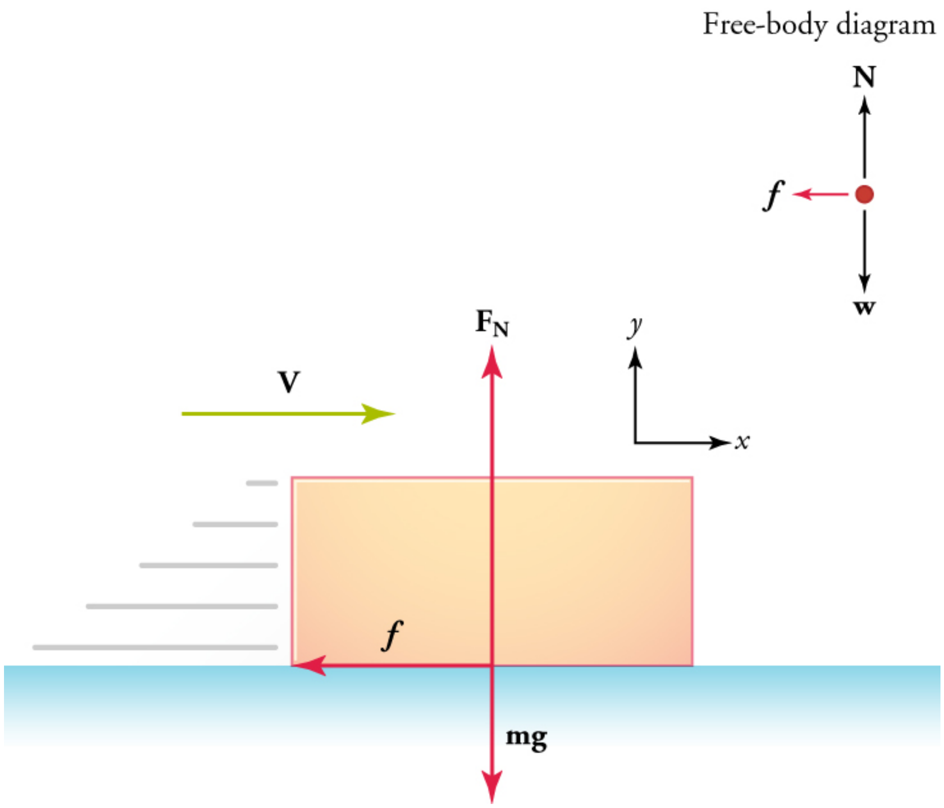

Figure 4.3 For a box sliding across a floor, friction acts in the direction opposite to the velocity.

The force of friction depends on two factors: the coefficient of friction and the normal force. For any two surfaces that are in contact with one another, the coefficient of friction is a constant that depends on the nature of the surfaces. The normal force is the force exerted by a surface that pushes on an object in response to gravity pulling the object down on a horizontal surface. In equation form, the force of friction is

$\mathbf{f} = \mu \mathbf{N}$,

4.1

where is the coefficient of friction and **N** is the normal force. (The coefficient of friction is discussed in more detail in another chapter, and the normal force is discussed in more detail in the section *Newton's Third Law of Motion*.)

Recall from the section on Force that a net external force acts from outside on the object of interest. A more precise definition is that it acts on the system of interest. A system is one or more objects that you choose to study. It is important to define the system at the beginning of a problem to figure out which forces are external and need to be considered, and which are internal and can be ignored.

For example, in Figure 4.4 (a), two children push a third child in a wagon at a constant velocity. The system of interest is the wagon plus the small child, as shown in part (b) of the figure. The two children behind the wagon exert external forces on this system (**F**1, **F**2). Friction f acting at the axles of the wheels and at the surface where the wheels touch the ground two other external forces acting on the system. Two more external forces act on the system: the weight **W** of the system pulling down and the normal force **N** of the ground pushing up. Notice that the wagon is not accelerating vertically, so Newton's first law tells us that the normal force balances the weight. Because the wagon is moving forward at a constant velocity, the force of friction must have the same strength as the sum of the forces applied by the two children.

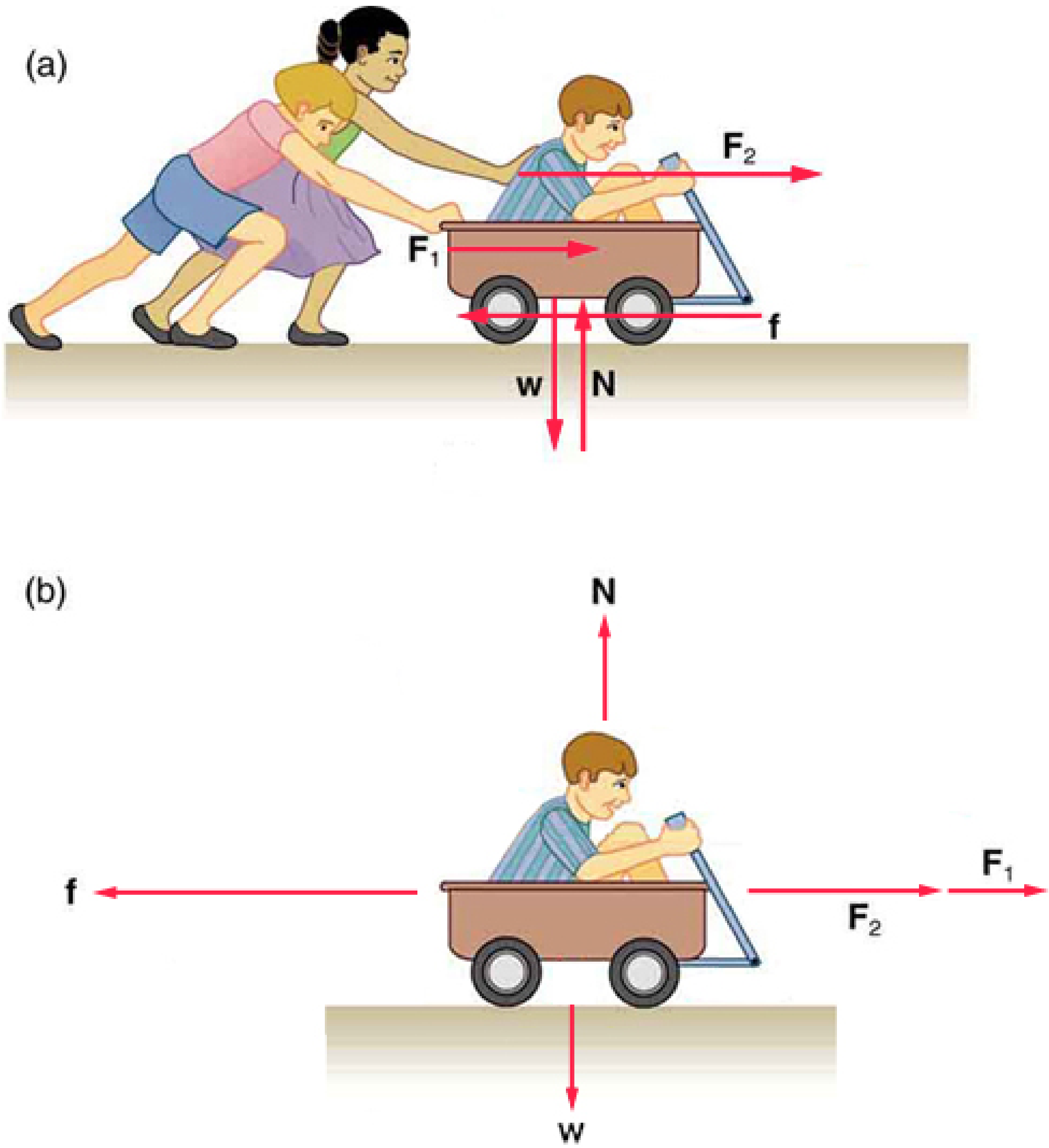

Figure 4.4 (a) The wagon and rider form a *system* that is acted on by external forces. (b) The two children pushing the wagon and child provide two external

forces. Friction acting at the wheel axles and on the surface of the tires where they touch the ground provide an external force that act against the direction of motion. The weight **W** and the normal force **N** from the ground are two more external forces acting on the system. All external forces are represented in the figure by arrows. All of the external forces acting on the system add together, but because the wagon moves at a constant velocity, all of the forces must add up to zero.

Mass and Inertia

Teacher Support

Teacher Support [BL] Review Newton's first law. Explain that the property of objects to maintain their state of motion is called inertia.

[OL][AL] Take two similar carts or trolleys with wheels. Place a heavy weight in one of them. Ask students which cart would require more force to change its state of motion. Ask students which would stay in motion longer if you were to set them in motion. Based on this discussion, have students speculate on what inertia may depend on.

[BL][OL] Explain the concepts of mass and weight. Explain that these terms may be used interchangeably in everyday life but have different meanings in science.

Inertia is the tendency for an object at rest to remain at rest, or for a moving object to remain in motion in a straight line with constant speed. This key property of objects was first described by Galileo. Later, Newton incorporated the concept of inertia into his first law, which is often referred to as the law of inertia.

As we know from experience, some objects have more inertia than others. For example, changing the motion of a large truck is more difficult than changing the motion of a toy truck. In fact, the inertia of an object is proportional to the mass of the object. Mass is a measure of the amount of matter (or *stuff*) in an object. The quantity or amount of matter in an object is determined by the number and types of atoms the object contains. Unlike weight (which changes if the gravitational force changes), mass does not depend on gravity. The mass of an object is the same on Earth, in orbit, or on the surface of the moon. In practice, it is very difficult to count and identify all of the atoms and molecules in an object, so mass is usually not determined this way. Instead, the mass of an object is determined by comparing it with the standard kilogram. Mass is therefore expressed in kilograms.

Tips For Success

In everyday language, people often use the terms *weight* and *mass* interchangeably—but this is not correct. Weight is actually a force. (We cover this topic in more detail in the section *Newton's Second Law of Motion*.)

Watch Physics

Newton's First Law of Motion This video contrasts the way we thought about motion and force in the time before Galileo's concept of inertia and Newton's first law of motion with the way we understand force and motion now.

Click to view content

Grasp Check

Before we understood that objects have a tendency to maintain their velocity in a straight line unless acted upon by a net force, people thought that objects had a tendency to stop on their own. This happened because a specific force was not yet understood. What was that force?

a. Gravitational force
b. Electrostatic force
c. Nuclear force
d. Frictional force

Virtual Physics

Forces and Motion—Basics In this simulation, you will first explore net force by placing blue people on the left side of a tug-of-war rope and red people on the right side of the rope (by clicking people and dragging them with your mouse). Experiment with changing the number and size of people on each side to see how it affects the outcome of the match and the net force. Hit the "Go!" button to start the match, and the "reset all" button to start over.

Next, click on the Friction tab. Try selecting different objects for the person to push. Slide the *applied force* button to the right to apply force to the right, and to the left to apply force to the left. The force will continue to be applied as long as you hold down the button. See the arrow representing friction change in magnitude and direction, depending on how much force you apply. Try increasing or decreasing the friction force to see how this change affects the motion.

Click to view content

Grasp Check

Click on the tab for the *Acceleration Lab and check the Sum of Forces* option. Push the box to the right and then release. Notice which direction the sum of forces arrow points after the person stops pushing the box and lets it continue moving to the right on its own. At this point, in which direction is the net force, the sum of forces, pointing? Why?

a. The net force acts to the right because the applied external force acted to the right.
b. The net force acts to the left because the applied external force acted to the left.
c. The net force acts to the right because the frictional force acts to the right.
d. The net force acts to the left because the frictional force acts to the left.

Teacher Support

Teacher Support Use the questions in *Check Your Understanding* to assess whether students have mastered the learning objectives of this section. If students are struggling with a specific objective, the *Check Your Understanding* assessment will help identify which objective is causing the problem and direct students to the relevant content.

Check Your Understanding

5.

What does Newton's first law state?

a. A body at rest tends to remain at rest and a body in motion tends to remain in motion at a constant acceleration unless acted on by a net external force.
b. A body at rest tends to remain at rest and a body in motion tends to remain in motion at a constant velocity unless acted on by a net external force.
c. The rate of change of momentum of a body is directly proportional to the external force applied to the body.
d. The rate of change of momentum of a body is inversely proportional to the external force applied to the body.

6.

According to Newton's first law, a body in motion tends to remain in motion at a constant velocity. However, when you slide an object across a surface, the object eventually slows down and stops. Why?

a. The object experiences a frictional force exerted by the surface, which opposes its motion.
b. The object experiences the gravitational force exerted by Earth, which opposes its motion
c. The object experiences an internal force exerted by the body itself, which opposes its motion.
d. The object experiences a pseudo-force from the body in motion, which opposes its motion.

7.

What is inertia?

a. Inertia is an object's tendency to maintain its mass.
b. Inertia is an object's tendency to remain at rest.
c. Inertia is an object's tendency to remain in motion
d. Inertia is an object's tendency to remain at rest or, if moving, to remain in motion.

8.

What is mass? What does it depend on?

a. Mass is the weight of an object, and it depends on the gravitational force acting on the object.
b. Mass is the weight of an object, and it depends on the number and types of atoms in the object.
c. Mass is the quantity of matter contained in an object, and it depends on the gravitational force acting on the object.
d. Mass is the quantity of matter contained in an object, and it depends on the number and types of atoms in the object.