4.1 Force

Section Learning Objectives

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

- Differentiate between force, net force, and dynamics
- Draw a free-body diagram

Teacher Support

Teacher Support The learning objectives in this section will help your 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:
  - (C) analyze and describe accelerated motion in two dimensions using equations, including projectile and circular examples;
  - (E) develop and interpret free-body diagrams.

[BL][OL] Point out that objects at rest tend to stay at rest. A ball, for example, moves only when pushed or pulled. The action of pushing or pulling is the application of force. Force applied to an object changes its motion.

[AL] Start a discussion about force and motion. Ask students what would happen if more than one force is applied to an object. Take a heavy object such as a desk for demonstration. Ask one student to push it from one side. Explain how force and motion work. Now ask a second student to push it in the opposite direction. Ask students why no motion occurs, even though the first student applies the same amount of force. Introduce the concept of adding forces.

Section Key Terms

Defining Force and Dynamics

Teacher Support

Teacher Support [OL] Explain that the word *dynamics* comes from a Greek word meaning *power*. Also point out that the word *dynamics* is singular, like the word *physics*.

[BL][OL] You may want to introduce the terms *system, external force*, and *internal force*.

[AL] Explain that both magnitude and direction must be considered when talking about forces.

Teacher Demonstration

By using physical objects, demonstrate how different forces acting together can be additive if they act in the same direction or cancel one another if they act in opposite directions. Explain the terms *acting on* and *being acted on*.

Force is the cause of motion, and motion draws our attention. Motion itself can be beautiful, such as a dolphin jumping out of the water, the flight of a bird, or the orbit of a satellite. The study of motion is called kinematics, but kinematics describes only the way objects move—their velocity and their acceleration. Dynamics considers the forces that affect the motion of moving objects and systems. Newton's laws of motion are the foundation of dynamics. These laws describe the way objects speed up, slow down, stay in motion, and interact with other objects. They are also universal laws: they apply everywhere on Earth as well as in space.

A force pushes or pulls an object. The object being moved by a force could be an inanimate object, a table, or an animate object, a person. The pushing or pulling may be done by a person, or even the gravitational pull of Earth. Forces have different magnitudes and directions; this means that some forces are stronger than others and can act in different directions. For example, a cannon exerts a strong force on the cannonball that is launched into the air. In contrast, a mosquito landing on your arm exerts only a small force on your arm.

When multiple forces act on an object, the forces combine. Adding together all of the forces acting on an object gives the total force, or net force. An external force is a force that acts on an object within the system *from outside* the system. This type of force is different than an internal force, which acts between two objects that are both within the system. The net external force combines these two definitions; it is the total combined external force. We discuss further details about net force, external force, and net external force in the coming sections.

In mathematical terms, two forces acting in opposite directions have opposite *signs* (positive or negative). By convention, the negative sign is assigned to any movement to the left or downward. If two forces pushing in opposite directions are added together, the larger force will be somewhat canceled out by the smaller force pushing in the opposite direction. It is important to be consistent with your chosen coordinate system within a problem; for example, if negative values are assigned to the downward direction for velocity, then distance, force, and acceleration should also be designated as being negative in the downward direction.

Free-Body Diagrams and Examples of Forces

Teacher Support

Teacher Support [BL] Review vectors and how they are represented. Review vector addition.

[AL] Ask students to give everyday examples of situations where multiple forces act together. Draw free-body diagrams for some of these situations.

For our first example of force, consider an object hanging from a rope. This example gives us the opportunity to introduce a useful tool known as a free-body diagram. A free-body diagram represents the object being acted upon—that is, the free body—as a single point. Only the forces acting *on* the body (that is, external forces) are shown and are represented by vectors (which are drawn as arrows). These forces are the only ones shown because only external forces acting on the body affect its motion. We can ignore any internal forces within the body because they cancel each other out, as explained in the section on Newton's third law of motion. Free-body diagrams are very useful for analyzing forces acting on an object.

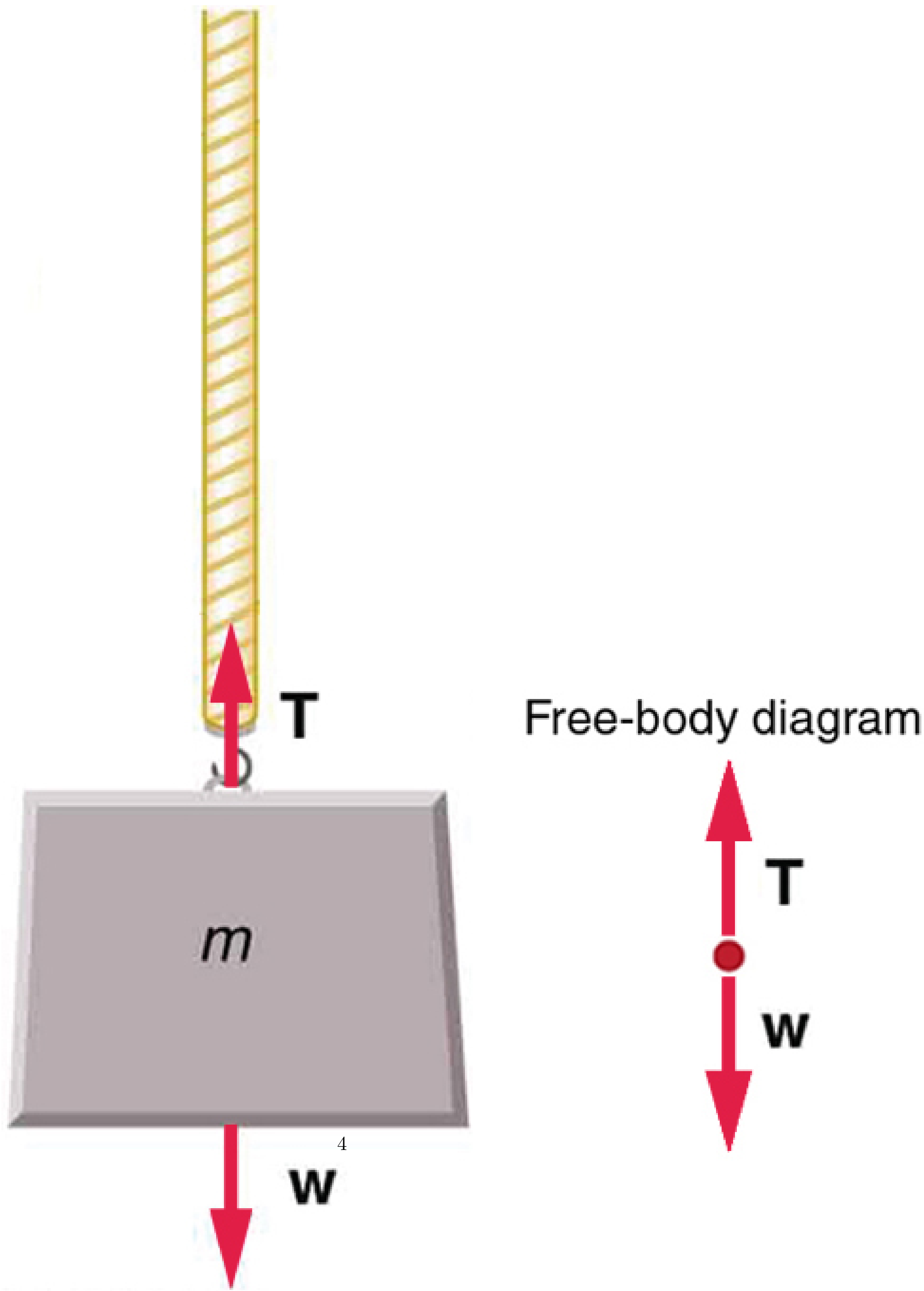
T
m
w
Free-body diagram
T
w

Figure 4.2 An object of mass, m, is held up by the force of tension.

Figure 4.2 shows the force of tension in the rope acting in the upward direction, opposite the force of gravity. The forces are indicated in the free-body diagram by an arrow pointing up, representing tension, and another arrow pointing down, representing gravity. In a free-body diagram, the lengths of the arrows show the relative magnitude (or strength) of the forces. Because forces are vectors, they add just like other vectors. Notice that the two arrows have equal lengths in Figure 4.2, which means that the forces of tension and weight are of equal magnitude. Because these forces of equal magnitude act in opposite directions, they are perfectly balanced, so they add together to give a net force of zero.

Not all forces are as noticeable as when you push or pull on an object. Some forces act without physical contact, such as the pull of a magnet (in the case of magnetic force) or the gravitational pull of Earth (in the case of gravitational force).

In the next three sections discussing Newton's laws of motion, we will learn about three specific types of forces: friction, the normal force, and the gravitational force. To analyze situations involving forces, we will create free-body diagrams to organize the framework of the mathematics for each individual situation.

Tips For Success

Correctly drawing and labeling a free-body diagram is an important first step for solving a problem. It will help you visualize the problem and correctly apply the mathematics to solve the problem.

Check Your Understanding

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.

1.

What is kinematics?

a. Kinematics is the study of motion.
b. Kinematics is the study of the cause of motion.
c. Kinematics is the study of dimensions.
d. Kinematics is the study of atomic structures.

2.

Do two bodies have to be in physical contact to exert a force upon one another?

a. No, the gravitational force is a field force and does not require physical contact to exert a force.
b. No, the gravitational force is a contact force and does not require physical contact to exert a force.
c. Yes, the gravitational force is a field force and requires physical contact to exert a force.
d. Yes, the gravitational force is a contact force and requires physical contact to exert a force.

3.

What kind of physical quantity is force?

a. Force is a scalar quantity.
b. Force is a vector quantity.
c. Force is both a vector quantity and a scalar quantity.
d. Force is neither a vector nor a scalar quantity.

4.

Which forces can be represented in a free-body diagram?

a. Internal forces
b. External forces
c. Both internal and external forces
d. A body that is not influenced by any force