Forces in detail

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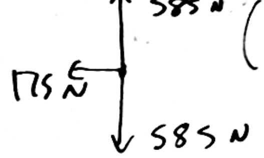


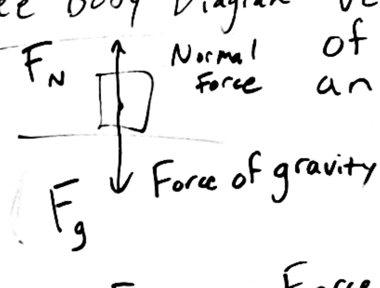
Force - a push or pull

measured in Newtons (N)

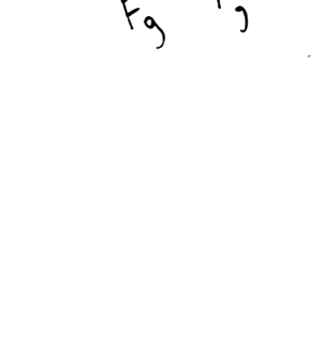
Force is a vector

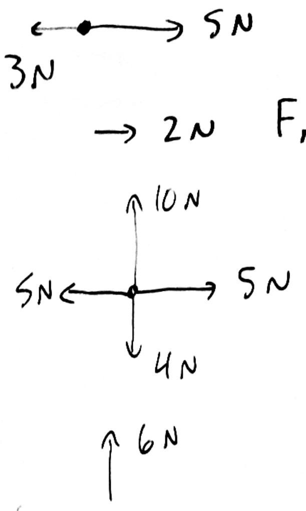
We can use free body diagrams to understand forces

(FBD) Free Body Diagram vector diagram of forces on an object



Normal Force - Force, Normal (perpendicular) to the surface





Gravity - Force of attraction between masses
(Ex: Earth)

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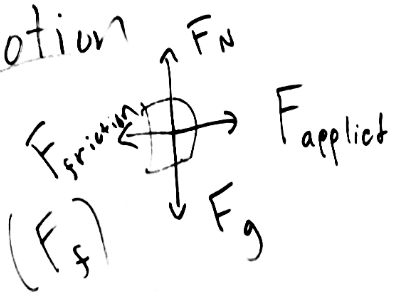
Friction - Force between surfaces, parallel to surface, opposes motion



Tension - Force in cord, string, rope, chain

4-1 Changes in motion

4-1 SECTION OBJECTIVES

- Explain how force affects the motion of an object.
- Distinguish between contact forces and field forces.
- Interpret and construct free-body diagrams.

force

the cause of an acceleration, or the change in an object's motion

FORCE

When we think of **force**, we usually imagine a *push* or a *pull* exerted on some object. For instance, you exert a force on a ball when you throw or kick it, and you exert a force on a chair when you sit in it. Force represents the interaction of an object with its environment.

Forces cause changes in motion

Notice that force is defined as causing a *change* in the motion of an object. Some examples of this are shown in **Figure 4-1.** In many cases, force does cause a stationary object to move, as when you throw a ball. Force also causes moving objects to stop, as when brakes stop your car or when a ball is caught. A force can also cause a moving object to change its direction, such as when you use the steering wheel to turn your car or when a tennis ball collides with a racket and bounces off in another direction.

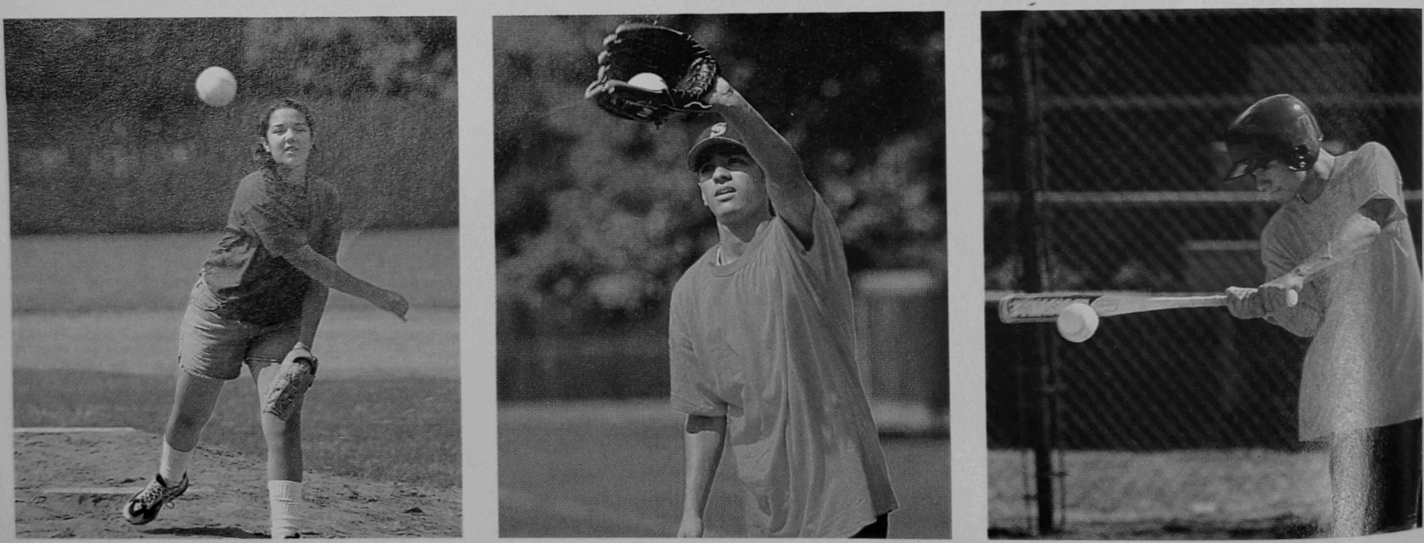


Figure 4-1
Force can cause objects to **(a)** start moving, **(b)** stop moving, or **(c)** change direction.

The SI unit of force is the newton

The SI unit of force is the newton, named after Sir Isaac Newton (1642–1727), whose work contributed much to the modern understanding of force and motion. The newton (N) is defined as the amount of force that, when acting on a 1 kg mass, produces an acceleration of 1 m/s^2. Therefore, 1 N = 1 kg × 1 m/s^2.

The weight of an object is a measure of the magnitude of the gravitational force exerted on the object. It is the result of the interaction of an object's mass with the gravitational field of another object, such as Earth. Many of the terms

Table 4-1 Units of mass, acceleration, and force

System	Mass	Acceleration	Force
SI	kg	m/s^2	$N = kg \cdot m/s^2$
cgs	g	cm/s^2	$dyne = g \cdot cm/s^2$
Avoirdupois	slug	ft/s^2	$lb = slug \cdot ft/s^2$

Did you know?

The abbreviation for the pound, lb, comes from *libra*, the Latin word for pound, a unit of measure that has been used since medieval times to measure weight.

and units you use every day to talk about weight are really units of force that can be converted to the SI unit of newtons. For example, a $\frac{1}{4}$ lb stick of margarine has a weight equivalent to a force of about 1 N, as shown in the following conversions:

$$1 \text{ lb} = 4.448 \text{ N}$$
$$1 \text{ N} = 0.225 \text{ lb}$$

Forces can act through contact or at a distance

If you pull on a spring, the spring stretches. If you pull on a wagon, the wagon moves. When a football is caught, its motion is stopped. These pushes and pulls are examples of **contact forces,** so named because they result from physical contact between two objects. This kind of force is usually easy to identify when you analyze a situation.

contact force

force that arises from the physical contact of two objects

Another class of forces—called **field forces**—does not involve physical contact between two objects. One example of this kind of force is the force of gravity. Whenever an object falls to Earth, it is accelerated by Earth's gravity. In other words, Earth exerts a force on the object, even when it is not in immediate physical contact with the object.

field force

force that can exist between objects, even in the absence of physical contact between the objects

Another common example of a field force is the attraction or repulsion between electrical charges. You can observe this force by rubbing a balloon against your hair and then observing how little pieces of paper appear to jump up and cling to the balloon's surface, as shown in **Figure 4-2.** The paper is pulled by the balloon's electric field.

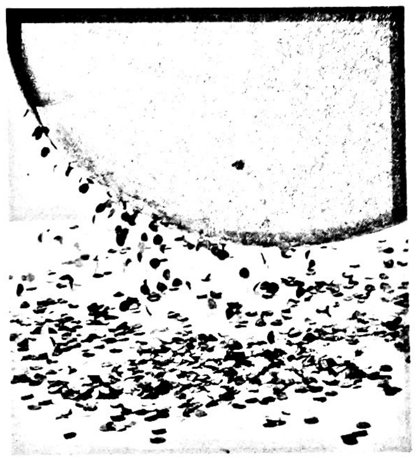


Figure 4-2
The electric field around the balloon exerts an attractive force on the pieces of paper.

The theory of fields was developed as a tool to explain how objects could exert force on each other without touching. According to this theory, the presence of an object affects the space around it so that a force is exerted on any other object placed within that space. This region of influence is called a field. Objects exert forces on one another when their fields come into contact. For example, an object falls to Earth because of the interaction between the object and the gravitational field of Earth.

Field forces are especially important in the study of particle physics. The known fundamental forces in nature, which act on elementary particles, are all field forces. This means that elementary particles have no actual contact—all their interactions are the results of field forces.

FORCE DIAGRAMS

If you give a toy car a small push, it will not move as far as it will when you give a harder push. The effect of a force depends on its magnitude, and the magnitude of the force of the second push is greater. The effect of a force on an object's motion also depends on the direction of the force. For example, if you push the toy car first from behind and then from the front, using the same amount of force each time, the car will move in a different direction each time.

Force is a vector

Because the effect of a force depends on its magnitude and direction, force is a vector quantity. Diagrams that show force vectors as arrows, like **Figure 4-3(a)**, are called **force diagrams.** In this book, the arrows used to represent forces are blue. The tail of the arrow is attached to the object on which the force is acting. These diagrams can be used as tools in analyzing collisions and other situations.

At this point, we will disregard the size and shape of objects and assume that all forces act on a point at the center of an object. In force diagrams, all forces are drawn as if they act on that point, no matter where the force is applied.

force diagram

a diagram of the objects involved in a situation and the forces exerted on the objects

A free-body diagram shows the forces on one object

Once engineers analyzing a test-car crash have identified all the forces involved, they isolate the car from the other objects in its environment. One of their goals is to determine which forces affect the car and its passengers. **Figure 4-3(b)** is a free-body diagram. It represents the same collision as the force diagram **(a)**, but it shows only the car and the forces acting on it. The forces exerted *by* the car on other objects are not included in the free-body diagram because they do not affect the motion of the car.

A free-body diagram is used to analyze only the forces affecting the motion of a single object. Free-body diagrams are constructed and analyzed just like other vector diagrams. In Section 4-2, you will learn to use them to find component and resultant forces. In this section, you will learn to draw a free-body diagram for situations in this book.

Quick Lab

Force and Changes in Motion

MATERIALS LIST

- ✔ 1 toy car
- ✔ 1 book

Use a toy car and a book to model a car colliding with a brick wall while traveling at a constant velocity. Observe the motion of the car before and after the crash. Identify as many changes in its motion, such as a change in speed or in direction, as you can. Make a list of all the changes, and try to identify the forces that caused them. Make a force diagram of the collision.

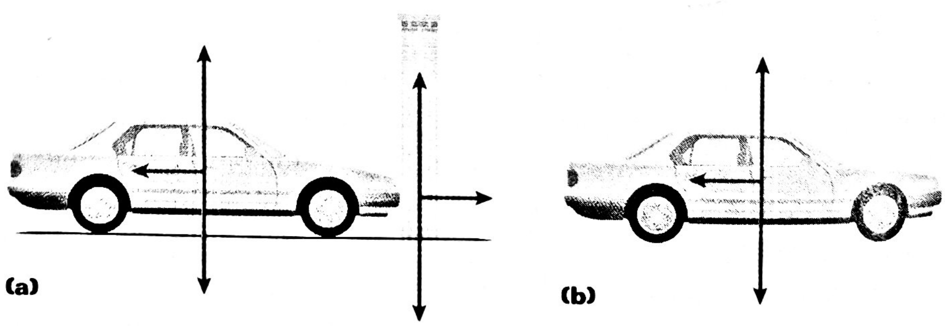


Figure 4-3
In a force diagram **(a)**, vector arrows represent all the forces acting in a situation. A free-body diagram **(b)** shows only the forces acting on the object of interest—in this case, the car.

A free-body diagram helps to analyze a situation

The photograph in **Figure 4-4(a)** shows a car being pulled by a tow truck. In a situation like this, there are many forces acting on the car. The tow truck exerts a force on the car in the direction of the cable, the road exerts forces on the car, and the car is also acted on by a gravitational force. The relationships between these forces help describe the motion of the car as it is being towed. A free-body diagram of the car will show all the forces acting on the car and how they affect the motion of the car as it is towed.

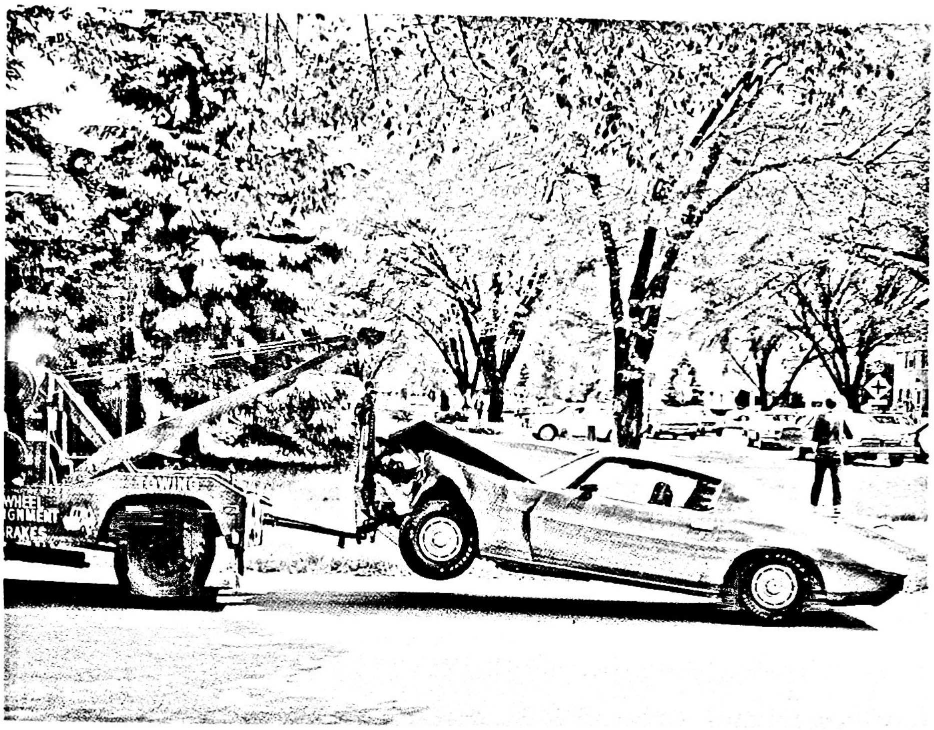


Figure 4-4(a)
The steps for drawing a free-body diagram to analyze the forces acting on this car are shown in **(b)** through **(f)**.

To draw a free-body diagram of the car, you must first isolate and identify all the forces acting on the car. The figures shown in **(b)** through **(f)** show all the steps required to draw a free-body diagram of the car. Following these general steps will allow you to draw a free-body diagram to isolate the forces acting on a single object for any situation. Before you begin identifying any of the forces acting in the situation, draw a diagram to represent the isolated object under consideration.

A simple diagram of the car is shown in step **(b).** It is often helpful to draw a very simple shape with some distinguishing characteristics that will help you visualize the object. In this case, the car is shown with a very simple shape that is positioned in the same way as the car in the photograph. Positioning the car in the same way will help you draw the arrows representing the forces in the correct positions. Free-body diagrams are often drawn using simple squares, circles, or even points to represent the object. In most cases in this book, free-body diagrams will use shapes that help you visualize the specific situations.

The next step is to draw and label vector arrows representing all external forces acting on the object. The diagram in **(c)** shows the force exerted by the towing cable attached to the car. The arrow is shown originating at the center of the car because all forces are assumed to act on a single point at the center of the object.

When you draw the arrow representing the force, it is important to label the arrow either with the size of the force or a name that will distinguish it from the other forces acting on the car. In this case, the force the tow truck exerts on the car is 5 800 N. The arrow is shown pointing in the same direction as the force of the cable on the car.

The gravitational force acting on the car is 14 700 N, directed toward the center of Earth. This force is shown in part **(d).** The road exerts an upward

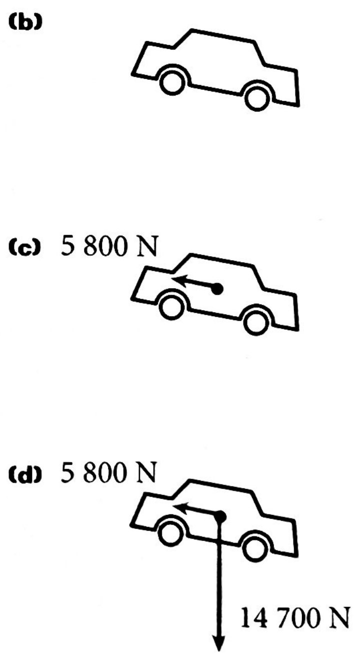
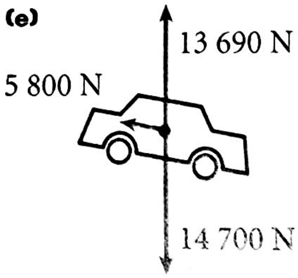


Figure 4-4(b–d)

(e)



(f)

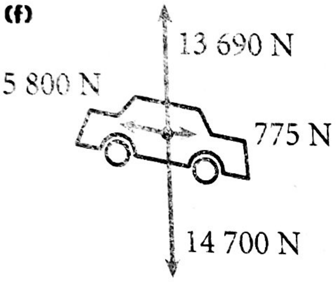


Figure 4-4(e–f)

force on the car equal to 13 690 N, as shown in part **(e)**. Because of the interaction between the road and the car's tires, the road also exerts a backward force on the car equal to 775 N, as shown in part **(f)**.

Make sure that only the forces acting on the car are included in your free-body diagram. Even though the car exerts forces on other objects, the only forces that should be included in the free-body diagram are the forces exerted on the car.

The figure in part **(f)** is the completed free-body diagram of the car being towed. Compare the free-body diagram to the car in the photograph. Although the two images of the car are very different, there is a strong resemblance between them. As you learn more about physics, the free-body diagram may begin to look more and more like the real image of the car because it reveals more information about the car in physics terms than the photograph does.

A free-body diagram can be used to find the net external force acting on an object, using the rules for vector analysis from Chapter 3.

Section Review

1. List three examples of each of the following:
   - **a.** a force causing an object to start moving
   - **b.** a force causing an object to stop moving
   - **c.** a force causing an object to change direction
2. Give three examples of field forces described in this section and three examples of contact forces you observe in everyday life. Explain how you know that these are forces.
3. Draw a free-body diagram of a football being kicked. Assume that the only forces acting on the ball are the force of gravity and the force exerted by the kicker.
4. **Physics in Action** Draw a force diagram of a crash-test dummy in a car at the moment of collision. For this problem, assume that the forces acting on the car are 19 600 N downward, 17 800 N forward, and 25 000 N backward. The forces acting on the dummy are 585 N downward, 175 N backward, and 585 N upward.
5. **Physics in Action** Use the information given above to draw a free-body diagram showing only the forces acting on the car in item 4. Label all forces.
6. **Physics in Action** Use the information given above to draw a free-body diagram showing only the forces acting on the dummy in item 4. Label all forces.