GAME DAY!

Imagine that you're playing in a soccer game. You receive a pass, dribble forward a few steps, and then shoot. The perfectly placed shot arches high over the goalie's outstretched fingertips and into the net.

Goal! But why did the ball move when you kicked it? Why did it fly in a curve over the goalie instead of continuing in a straight line? Answering questions like these requires us to investigate the mysterious world of forces.

4.1 INTRODUCTION TO FORCES

ESSENTIAL QUESTION IF A FORCE IS A PUSH OR A PULL, HOW CAN FORCES BE BALANCED?

Questions

- What is a force?
- Are forces and energy related?
- What is the difference between balanced and unbalanced forces?
- How can I predict an object's motion on the basis of the forces acting on it?
- Why is motion predictable?

Terms

force
work
balanced forces
unbalanced force

Force

The simple answer to the questions in the chapter opener is that forces were at work on the soccer ball. A **force** is a push or a pull on an object. When a force is pushing or pulling something, we say that the force is *exerted* on the object. The metric unit for forces is the *newton*, which is abbreviated as N. In the soccer scenario the most obvious force being exerted happens when you kick the ball. Your foot exerts a force on the ball, and the ball moves as a result. There are other, less obvious forces at work in that scenario as well. The muscles in your leg exert forces on your bones to move your leg and foot. Gravity exerts a downward force on the ball in flight. Friction and air resistance work to slow down the ball as it moves. We'll look at these kinds of forces and others in the sections that follow.

Another thing to note about the soccer scenario is the *motion* of the ball. Remember, motion is a change in an object's position. In this case the ball's motion changed from rolling along the ground as you dribbled it to flying through the air after you kicked it. Your kick—the force you exerted—changed the motion of the ball. That's usually what a force does: it changes the motion of the object that it's exerted on. An object's motion can be changed in one of three ways. Like a soccer kick, a force can start an object moving or make it go faster. A force can also make an object go slower or even come to a stop, like receiving a pass. Lastly, as when deflecting a corner kick, a force can change the direction of an object's motion.

Forces, Energy, and Work

Recall that energy is the ability to do work. Since the soccer ball is in motion, it has kinetic energy. Kinetic energy is the energy of motion. When you kick a ball, you apply a force, which adds kinetic energy. A scientist would say that you did work on the ball. Scientists define the concept of work in two different ways. **Work** is a change in energy, and work is done when a force moves an object over a distance. How does this apply to the soccer game in the chapter opener?

Sports, like soccer, require energy. In soccer, we add or remove energy by applying forces with our feet when kicking the ball. Think about the kicked ball again. As you kicked it, your kicking foot was in motion. That means that it had kinetic energy. The rolling ball had kinetic energy too. But when you kicked the ball, it flew away, moving faster than it did before. It had more kinetic energy after you kicked it. Where did that extra kinetic energy come from? It had to come from your foot! You did work on the ball by applying a force over a distance. That tells us that kinetic energy can be transferred from one object to another as a force is exerted. The amount of energy transferred depends on the strength of the force and the distance over which it is exerted. A strong force exerted over a short distance may have the same effect as a weaker force exerted over a longer distance. We can apply a force over a distance of one centimeter, and the ball will roll away slowly. But if we apply the same force over a distance of ten centimeters, the ball will fly away with greater speed.

Let's think about another example from the world of sports. Think about throwing a baseball or softball. This time, it's your hand that exerts a force on the ball as you throw it. Your hand does work on the ball. But think about the distance involved. Does your hand contact the ball over a longer or shorter distance compared to kicking a ball? Your hand is in contact for a longer distance! This explains why professional baseball pitchers can routinely throw fastballs at 95 mph (153 kph).

Balanced and Unbalanced Forces

You've probably played tug-of-war before. Imagine a team in blue playing tug-of-war against a team in red. The blue team pulls with all their might in one direction, while the red team does the same but in the opposite direction. If the two teams are equally matched, the flag tied to the middle of the rope may remain motionless. How is that possible if both teams are exerting large forces on the rope?

The rope in our imaginary game of tug-of-war doesn't move because the forces acting on it are *balanced*. **Balanced forces** occur when two or more forces are exerted so that the forces cancel out, or balance, each other. Balanced forces can't change the motion of the object on which they act. To change an object's motion, the forces acting on it must be *unbalanced*. **Unbalanced forces** occur when one force acting on an object is greater than the other forces. If there is only one force on an object, it is always unbalanced. An unbalanced force always changes an object's motion. Your kicked soccer ball is an example of an unbalanced force in action. The force that your foot exerted on the ball was greater than the other forces acting on it, so the ball moved in the direction your foot sent it. Likewise, the tug-of-war rope stays motionless, but when one team weakens, creating unbalanced forces, the rope will move one way or the other.

Predicting Motion

Now that we know how forces can affect motion, we can use that knowledge to predict how an object's motion will change when a force acts on it. Will it speed up, slow down, or change direction? Or will it do some combination of those things? To make our determination, we need to consider a few simple questions.

Are the forces balanced or unbalanced? Remember, only an unbalanced force can change an object's motion.

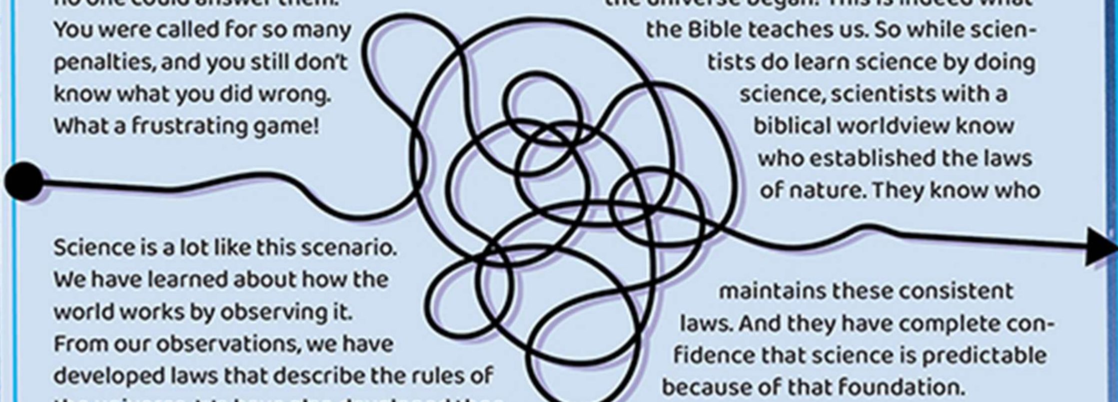
If there is an unbalanced force, in which direction is it acting?

CASE STUDY

Order or Chaos?

Imagine that you had never played soccer and your friends told you that their team needed one more player. You had heard them talk about soccer and were excited to learn the game. Before the first game you decided to do some research about the rules. But then you discovered that there was no information about the rules. You couldn't even find out who made the rules! You contacted the coach, and he told you that no one knows where the rules came from. He also said that he couldn't tell you the rules. Everyone just learns the rules as they play the game.

Just as you feared, that first game was really confusing! You had so many questions, but no one could answer them. You were called for so many penalties, and you still don't know what you did wrong. What a frustrating game!



Science is a lot like this scenario. We have learned about how the world works by observing it. From our observations, we have developed laws that describe the rules of the universe. We have also developed theories to explain why things happen. This discovery of how the world works is the whole point of science. But why does the universe behave as it does? Where did the natural laws come from? Who wrote the rules?

How do scientific naturalists account for order in the universe? If the universe is a product of pure chance, without any assistance from God, then there is really no sound reason why the universe is orderly instead of chaotic. Naturalists say that the laws governing nature just had to be how they are. They also say that at different times the laws were different but can't explain how or why the laws changed. While scientific naturalists can observe the present laws in action, they can't explain where the laws came from or why they exist.

Happily for us, our universe *does* operate in an orderly and predictable fashion. Our world operates according to certain laws, some of which we are learning about in this textbook. Christians have always believed that this order flows from God, the Creator of both our universe and its governing laws. He is not a god of chaos! In addition, the creation's laws had to be in operation from the very beginning—which means that the one who created the laws had to exist *before* the universe began! This is indeed what the Bible teaches us. So while scientists do learn science by doing science, scientists with a biblical worldview know who established the laws of nature. They know who maintains these consistent laws. And they have complete confidence that science is predictable because of that foundation.

So the next time a soccer ball you kick moves in the direction that you aimed rather than orbiting your teammate, thank God for creating rules for orderly motion!

Questions to Consider

1. Compare the biblical worldview and naturalistic worldview explanations for why our world is orderly and predictable.
2. Reflect on God's gift of order in the universe; then write one or two sentences to express your thanks to Him.

mini LAB

Balancing Act

ESSENTIAL QUESTION ARE BALANCED FORCES ALWAYS EQUAL IN STRENGTH?

Is it true that balanced forces will not change an object's motion? Let's find out!

Procedure

A Hook two spring scales together so that you and a partner can pull them in opposite directions.

B While your partner keeps his or her spring scale steady, pull on your spring scale until your partner's scale reaches 10 N.

1. What does the N in 10 N represent?
2. At this point, are your spring scales in motion or steady, that is, motionless?
3. How much force does your spring scale read?

Equipment

- spring scales, 20 N (3)

Now think about what might happen if you hook two spring scales to your partner's scale. If you repeat Step B while pulling on two spring scales, will they read the same amount of force as before?

4. Make a prediction about how much force will be read on the two spring scales. Will each read more force, less force, or the same amount of force as in Step B?

C Repeat Step B by pulling on the two spring scales that are connected to your partner's spring scale.

5. Was your prediction in Question 4 correct? Explain.
6. What is the *combined* force value of the paired scales?
7. Write a summary of what you have learned from this exercise about the strengths of the balanced forces acting on an object.

4.1 SECTION REVIEW

1. What is a force?
2. How are force and energy related?
3. What two factors determine how much the kinetic energy of an object will change when a force is exerted on it?
4. Which type of forces can change an object's motion, balanced or unbalanced?
5. A student pushes a stationary lab cart with 50 N of force to the left. At the same moment a second student pushes on the other side of the cart with 45 N of force to the right. How will the cart's motion change in response to these forces?

4.2 TYPES OF FORCES

ESSENTIAL QUESTION DO OBJECTS HAVE TO BE TOUCHING TO EXERT A FORCE ON EACH OTHER?

Have you ever moved a magnet closer and closer to another magnet sitting on a desk? Suddenly, the second magnet leaps toward the magnet in your hand—snap! It moves without you touching it. But you *do* have to touch a soccer ball in some manner to get it to move. This suggests that there are at least two kinds of forces at work in our world. Are there more?

One way to classify forces is based on whether objects must touch for the force to be exerted. A **contact force** is a force that acts only when two objects touch, or contact, each other. A **field force** can act over a distance—an object does not have to touch another object to exert a force on it. Field forces are sometimes called *noncontact forces*. Two important field forces are gravity and electromagnetism. We'll examine those two forces in the next two sections. For now, let's consider some examples of contact forces.

Questions

- How can I determine what kinds of forces are at work on an object?
- How are contact and field forces different?
- How can I show the forces that are acting on an object?

Terms

contact force
field force
free-body diagram

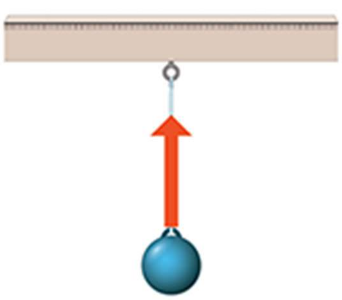
CONTACT FORCES

NORMAL FORCE

Remember that unbalanced forces always change an object's motion. Now think about yourself standing on the ground. Is gravity acting on you as you stand there? Of course it is! Yet you don't sink into the ground as a result. As gravity pulls you toward the earth, the earth must push back with equal force. The force that a surface exerts against an object touching that surface is called the *normal force*.

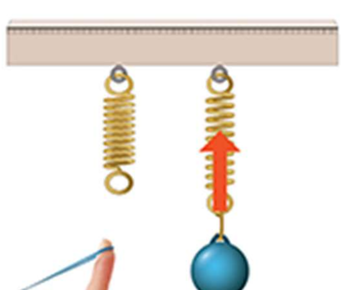
TENSION

Tension is a pulling force. It is transmitted through a line of some kind. The rope in a game of tug-of-war transmits a tension force between the two teams.



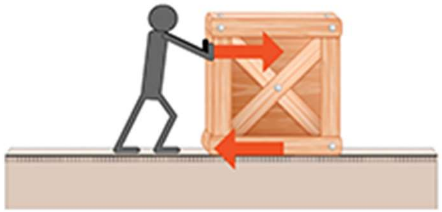
ELASTIC FORCE

An *elastic force* allows an object to return to its original shape after being deformed. You can stretch a rubber band, but it will go back to its original shape when you let go.

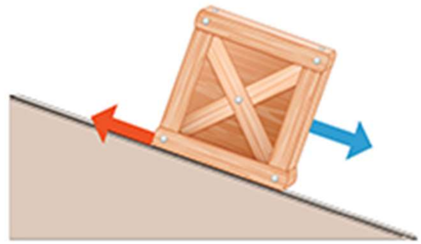


FRICTION

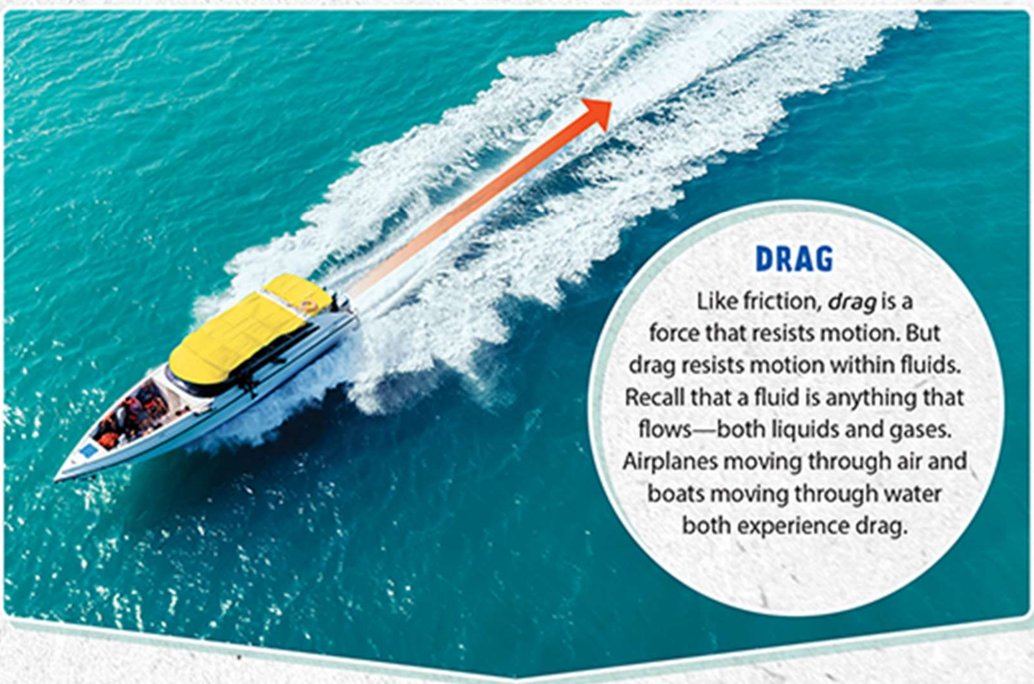
Friction is a force that resists the movement of objects that are in contact and trying to move past each other. There are different types of friction.



Static friction is the kind that tends to keep a nonmoving object in its place when it is trying to slide. It explains why you can hold a book on the palm of your hand, tilt your hand, and not have the book slide off.



Sliding friction occurs when two objects are moving past each other. Depending on the situation, sliding friction can be good or bad. Sliding friction causes wear and tear on things with moving parts, like car engines. But sliding friction also makes lighting household matches possible.



DRAG

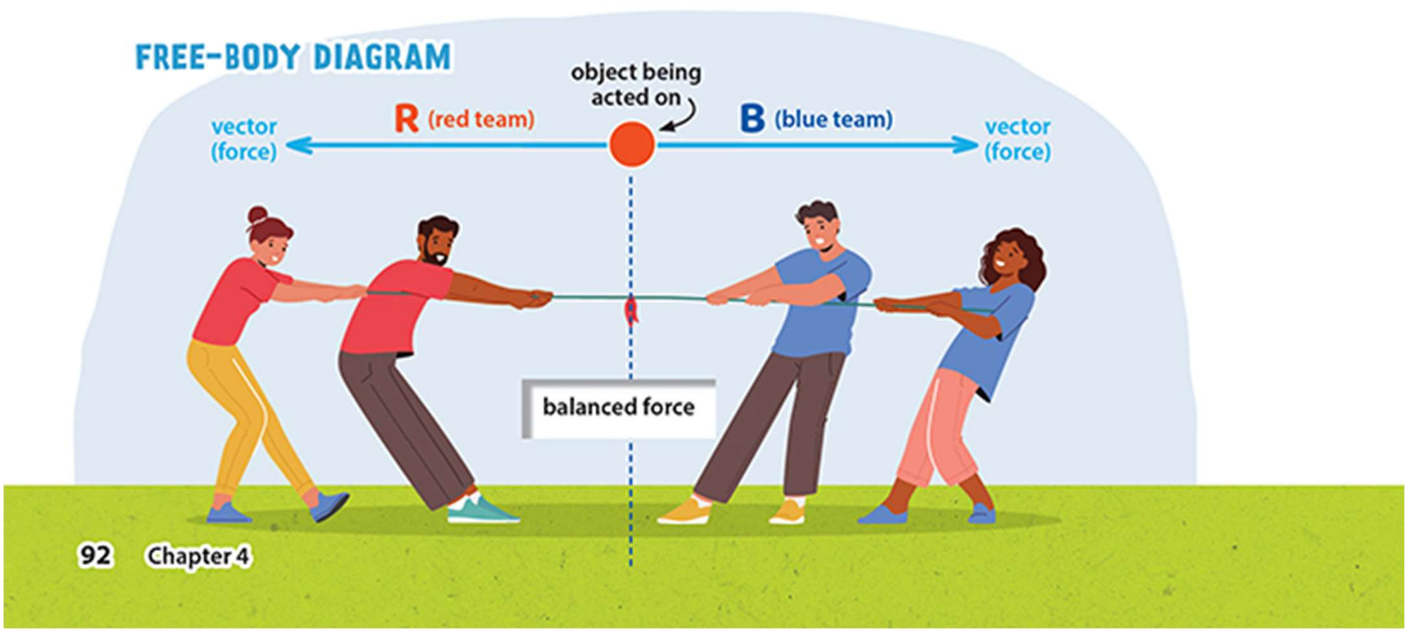
Like friction, *drag* is a force that resists motion. But drag resists motion within fluids. Recall that a fluid is anything that flows—both liquids and gases. Airplanes moving through air and boats moving through water both experience drag.

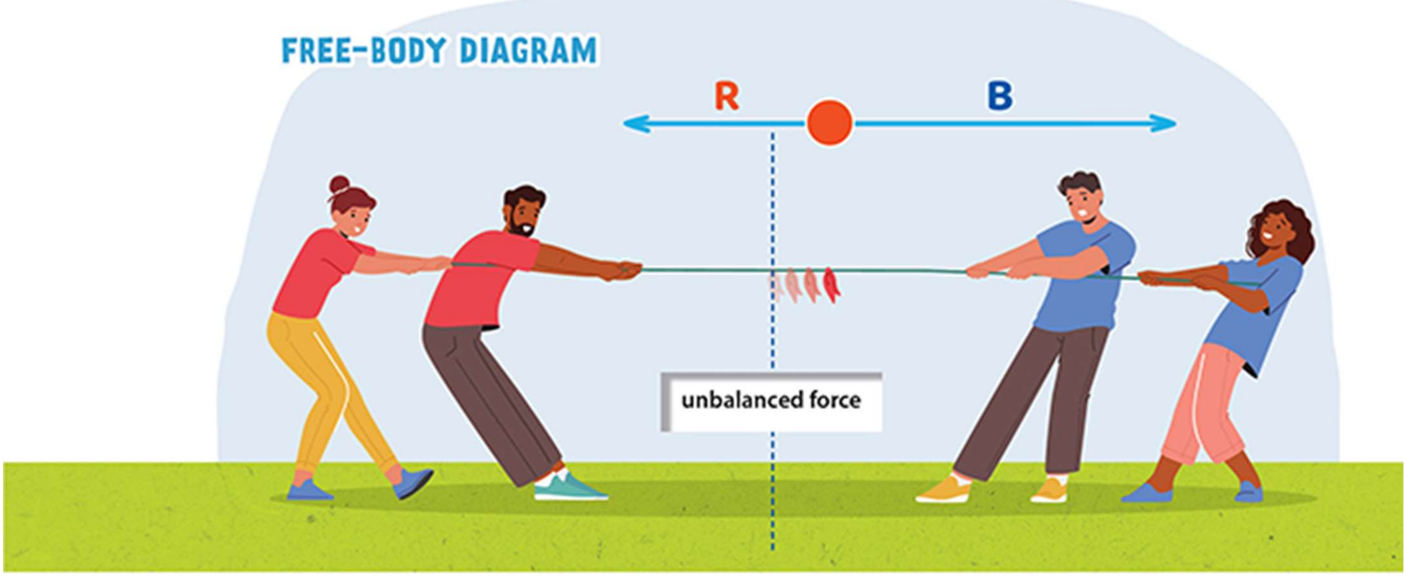
Force Diagrams

In the real world there are usually more than just two forces acting on an object at one time. Most of the time those forces act in different directions. Sometimes those forces are balanced, resulting in no change to an object's motion. At other times, though, those forces don't cancel each other completely. When that happens, the result is some amount of unbalanced force, called the *net force*, acting in a single direction. The net force is the sum, or total, of all the forces acting on an object.

One way to analyze the forces acting on an object is to create a diagram. A **free-body diagram** is a model that shows an object and the forces acting on it. Forces are *vectors*, meaning that they have a measurable size, or magnitude, and a measurable direction. We use arrows to represent vectors, so each force is shown as an arrow. The arrow points in the direction in which the force is acting. The length of the arrow represents the amount of force being exerted. Note also that the arrow always points *away* from the object being acted on, even if the vector represents a push.

Think back to the tug-of-war we described earlier. We can use a free-body diagram to show the balanced forces exerted by the two teams. We'll show the blue team's force as **B** and the other as **R**. If each team pulls with equal force in opposite directions, the free-body diagram of the contest looks like what you see below. Since the forces exerted are equal, the vector arrows are drawn the same length. And since the forces are in opposite directions, canceling out each other, we say that there is a *zero net force* acting on the rope. The forces are balanced.





Now suppose the red team begins to tire. Suddenly the forces acting on the rope are no longer balanced. We say that the forces are *unbalanced*. The red team now exerts less force, **R**, on the rope, so its vector on the free-body diagram shortens. There is now a *nonzero net force* acting in the direction of the blue team. The **B** arrow is now longer than the **R** arrow since the blue team is pulling harder than the red team and thus is applying a larger force. Unless the red team can add some force, the blue team is going to win!

4.2 SECTION REVIEW

1. Which type of force, contact or field, can be exerted if two objects are not touching?
2. Describe two forces acting on a cat sitting on a bookcase. Identify the direction in which each force acts and whether it is a contact or field force.
3. A rider on a bicycle gently applies the brakes as she rolls down a hill. Which type of force occurs between the brake pads and the wheel?
4. Fish are designed to move easily through water. Which type of force does the design of their bodies reduce?
5. Refer to the setup of the three spring scales described in the mini lab on page 88. Draw a free-body diagram of the three forces at work in that scenario. Label the single force as A. Label the paired forces as B and C. *Hint:* Think carefully about the lengths of the vector arrows!
6. Imagine two forces acting on an object, each with 5 N of force. The **U** force is exerted upward. The **L** force is exerted to the left. Draw a free-body diagram for the two forces.
7. Will the forces described in Question 6 change the object's motion? If so, in what direction will the net force be exerted?