Review 10

Force and Motion

Just as Alicia was about to kick the soccer ball, Kim said, "It won't go anywhere."

This threw Alicia off her stride. She stopped and glared at her sister. "What did you say?"

"The soccer ball. It won't go anywhere. That's Newton's third law. When you kick the ball, you're exerting a force on the ball, right? But the ball also exerts a force that's equal and opposite to your kick. So, the forces cancel each other out. The ball won't go anywhere."

Alicia thought about this for a moment. Then she kicked the ball, which flew into the goal. "I'm not sure you've got that third law quite right," she said, smiling.

Newton's First Law

Scientists used to believe that the "natural" state of an object on the Earth was to be at rest. They also believed that objects in motion on the Earth required a force to keep them in motion. Isaac Newton, however, showed that this was not true. **Newton's first law of motion** states that an object will keep doing what it is doing (staying still, moving) if the forces acting on it are balanced (equal and opposite). This means that an object that is not moving will continue to not move. However, it also means that an object that moves (1) at a constant speed and (2) in a straight line will continue that motion unless the forces acting on it are unbalanced. Because an object's resistance to a change in its motion is called **inertia**, Newton's first law of motion is sometimes called the law of inertia. An object's mass is a measure of its inertia.

Gabe kicked a soccer ball across a field. The ball rolled for a while but eventually stopped. If Newton's first law is true, it seems that the ball Gabe kicked should continue rolling forever. Why does the ball stop?

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Words to Know

- acceleration
- contact force
- force
- friction
- gravity
- inertia
- net force
- newton
- Newton's first law of motion
- Newton's second law of motion
- Newton's third law of motion
- noncontact force
- normal force

Once an object is in motion, it stays in motion until it is acted on by another force. When you roll a ball, it is slowed by friction and will eventually stop. When an airplane moves through the sky, resistance from the air acts to slow it down. Outer space, however, is a different environment with practically no friction and absolutely no air resistance. In outer space, a moving object will keep going, practically forever. So remember: Don't let go of the tether the next time you are on a spacewalk!

Suppose you are playing baseball and hit a home run. What forces slow down the ball while it is in motion?

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If you hit the home run in space, what would happen? ____

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Describing Motion

Scientists have many ways of describing an object's motion: position, speed, direction, acceleration, and so on. On the Earth, an object's motion rarely stays constant. When an object's speed or direction changes, the object undergoes an **acceleration**. When most people use the word accelerate, they mean "to speed up." When scientists use the word accelerate, they mean *any* change in either the speed or the direction of an object's motion.

Scientists often express acceleration with the units "meters per second for each second," or "meters per second squared" (m/s^2). Does it seem strange to "square" a second? All this means is that the speed (m/s) is changing at a constant rate for each unit of time (s) that passes. Suppose that an object moving at 2 m/s starts accelerating at 1 m/s^2. After 1 s, the object has a speed of 3 m/s. After 2 s, the object has a speed of 4 m/s. The object's speed increased by 1 m/s for each second that passed.

Suppose that Sharon rides her bike at a speed of 10 m/s. As she rides up a hill, her speed decreases to 5 m/s. Is her acceleration positive or negative?

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Now, suppose Sharon rides her bike down the street in 20 seconds. During this time, her speed remains constant at 5 m/s. What is the value of her acceleration during this time?

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So, what causes an object to accelerate—in other words, to go faster, or slower, or in a different direction? Only a force can do this. A **force** is a push or a pull that can cause the motion of an object to change.

Give an example of a situation in which you apply a force to something and it does the following.

Goes faster: ______________________________

Goes slower: ______________________________

Changes direction: ______________________________

A **contact force** must touch an object to change its speed or direction. When a bat hits a ball, they exert a contact force on each other, causing the speed and direction of both to change. One example of a contact force is **friction**, which slows down objects due to particles of two materials catching on each other. **Normal force** is the force exerted by an object to balance an outside force acting on it. This is easier than it sounds: When you sit in your chair, the chair exerts a normal force on your body that is equal to the force of gravity pulling your mass toward the Earth.

Dave is driving down the street. If Dave steps on the brakes, what force slows his car?

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Some forces, called **noncontact forces**, can act on objects from a distance. For example, **gravity** is a force that pulls two objects with mass toward each other. The size of the gravitational force depends on two things: the masses of the objects and the distance that the objects are from each other. The more mass an object has, the greater the force of gravity it can exert on other objects. The closer objects are to each other, the greater the force of gravity the objects will exert on each other. Gravity from the center of the Milky Way galaxy influences the movements of our solar system, which is thousands of light-years away. Gravity is a universal force, meaning that every object that has mass exerts gravitational pull on every other mass. Everything on or near the Earth is pulled toward the Earth's center by the gravitational force. Magnetism and electricity are other examples of noncontact forces.

What force causes a ball to speed up as it rolls down a hill?

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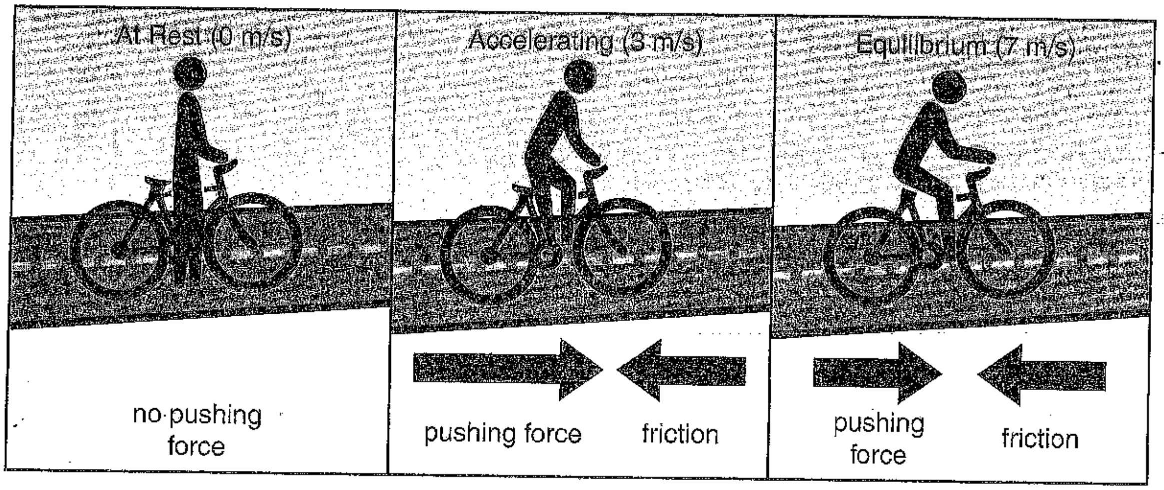
Newton's Second Law

Newton determined the relationship between the forces acting on an object and the object's motion. **Newton's second law of motion** states the following: The acceleration of an object is related to the net force acting on it and the object's mass. In the metric system, the units for force are kg × m/s^2. Scientists have given this group of units a simple name: the **newton (N)**. Many forces can act on an object at the same time. When you add up all of the forces, you get the **net force**. If all of the forces acting on the same object add up to 0 N, the forces are balanced. If the forces are balanced, then the object is at rest or moving in a straight line at a constant speed. If the net force is anything other than 0 N, the forces are unbalanced. If the forces are unbalanced, then the object is accelerating—its speed and/or its direction is changing.

It is easy to grasp that the net force for an object at rest is zero. It may be harder to see how objects moving at a constant speed in a straight line also have a net force of zero. This idea becomes clearer when you consider Sharon on her bicycle. Look at the diagram below.



In the first panel, Sharon is at rest. In the second panel, she starts accelerating. To start moving, the first few pushes she gives the pedals must provide a force that is greater than the friction from the road. In other words, the pushing and friction forces are unbalanced. A net force greater than zero acts in the direction of her motion to make her go faster. By the third panel, Sharon's pushing force is equal to the force of friction from the road. The forces are balanced, the net force is zero, and Sharon moves at a constant speed in a straight line.

Sharon cruises east at 7 m/s. She then uses her brakes and comes to a gentle stop. As Sharon slows, how does the direction of the net force compare to that of her motion?

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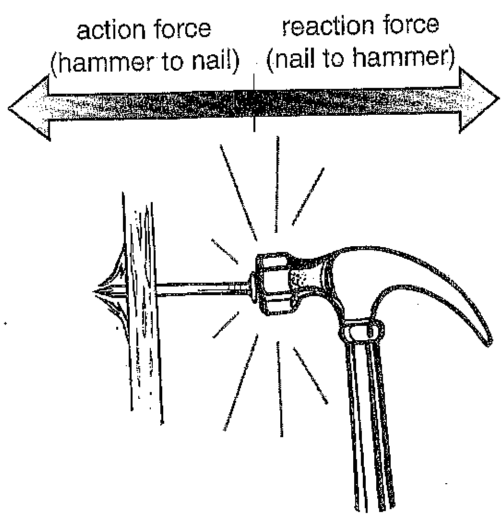
Newton's Third Law

Newton's third law of motion states that forces come in pairs: For every action, there is a reaction that is equal in magnitude (size) but opposite in direction. This sometimes confuses people: If the forces are equal and opposite, then why don't they cancel each other out? How does anything move? The key is to remember that the "equal and opposite" forces act on *different* objects, often with greatly different masses.

As an example, look at the picture of a hammer pounding a nail into a board. The hammer supplies an action force, one that pushes on the nail toward the left. The nail supplies a reaction force, one that is equal to the action force and pushes on the hammer toward the right. Because the hammer is more massive than the nail, the nail moves away from the point of contact, into the wood. However, the same amount of force works on the hammer by stopping it; there might even be a slight rebound as the hammer moves away from the point of contact. That is the reaction force that the nail exerts on the hammer.



Think back to the story of Alicia and the soccer ball. Using Newton's third law of motion, explain how she could kick the ball into the goal.

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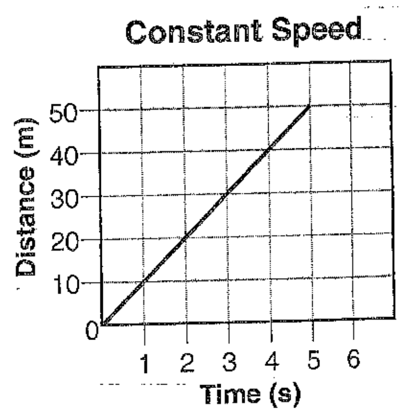
We've spent a lot of time talking about speed, distance, and acceleration. Let's look at how to graph them.

Graphing Motion

Speed and acceleration can be expressed on graphs. Take a look at the graph to the right. This is called a distance-time graph, because the *y*-axis shows distance, and the *x*-axis shows time. Suppose that an object moves at a constant speed. The line on the graph represents the distance the object moves in an amount of time. At 1 s the object has moved 10 m, at 2 s the object has moved 20 m, and so on.



On a distance-time graph, a straight line means that the speed is constant. In the example above, the object neither speeds up nor slows down. If you want to find the speed of the object, just find the slope of the line. First, pick two points—an initial point with the coordinates (t_i, d_i) and a final point with the coordinates (t_f, d_f). Put these coordinates into the following equation.

$$\text{slope of the line} = \frac{d_f - d_i}{t_f - t_i} = \frac{\Delta d}{\Delta t} = \text{speed in m/s}$$

Notice that the values for distance (m) are in the numerator, and the values for time (s) are in the denominator. This results in the proper units for speed: distance over time.

Use the formula for slope to find the speed of the object in the graph on page 112.

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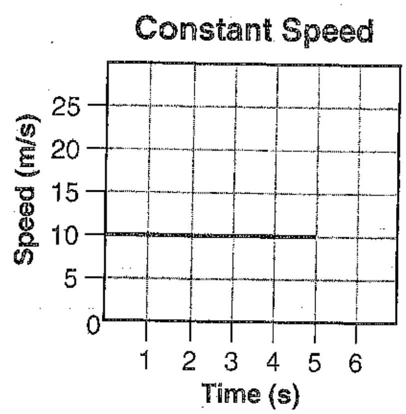
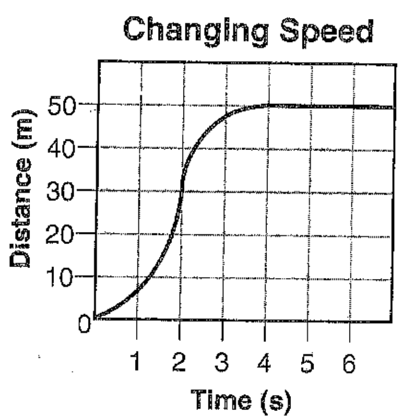
Another type of graph, called a speed-time graph, puts speed on the *y*-axis and time on the *x*-axis. A speed-time graph for the example on page 112 would look like the graph to the right. This graph shows that the speed of the object is constant at 10 m/s. But on the Earth, speed is rarely constant: Acceleration happens all the time. Let's look at how to depict changes in speed on distance-time and speed-time graphs.



On a distance-time graph, a curved line means that an object's speed changes over time. Look at the distance-time graph below. The slope of the line increases between 0 s and 2 s. This means that the speed of the object is increasing. Then, the slope of the line gradually decreases from 2 s to 4 s. This means that the object is slowing down.



What is the slope of the line between 4 s and 6 s? What does this say about the object's speed?

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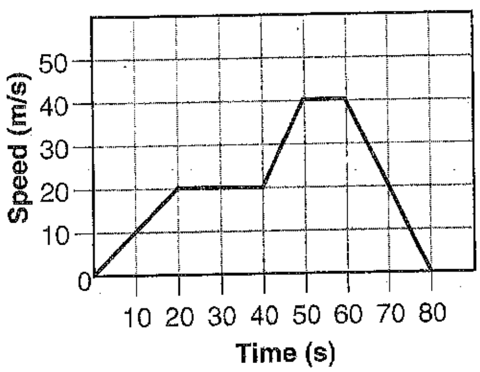
On a speed-time graph, a line with a positive slope represents an increase in speed, a horizontal line represents constant speed, and a line with a negative slope represents a decrease in speed.

The speed-time graph below shows an object. The speed at which the object is moving keeps changing. Study the graph, then answer the questions.



Identify all of the time intervals when the object is speeding up, slowing down, or keeping a constant speed.

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Identify the speed of the object between 20 and 40 s. ________________________

Keys to Keep

- **A force is a push or a pull that can cause a change in the speed and/or direction of an object's motion.**
- **If the forces acting on an object are balanced, then the object's motion will not change.**
- **If the forces acting on an object are unbalanced, then the object's speed and/or direction will change.**
- **You can measure and graph the motion of an object.**

Explore It Yourself

Joan lives in a rural area of New Jersey. For exercise, she rides her bike to a small pond 5 km from her house. Sometimes she swims in the pond, but today she just rests for a short time before heading back home. The entire trip, including time spent at the pond, takes Joan 50 minutes. The following table shows the time intervals during the trip and the distance she travels during those intervals.

Joan's Bike Ride

Time Interval (min)	Distance Traveled During Interval (km)
0–4	1
4–13	3
13–14	1
14–24	0
24–34	1
34–50	4

Using the data from the table, make a graph showing the total number of kilometers that Joan traveled during her trip. Look back at the review to decide whether time should go on the *x*- or the *y*-axis. Be sure to label your *x*- and *y*-axes, indicate what units you are using, and give your graph a title.

What Does It Mean?

1. On a distance-time graph, the slope of the line is related to speed. The steeper the slope, the faster the speed. During her trip, Joan must ride down a very steep hill, and then walk her bike up that same hill on her return. From your graph, determine the time interval in which Joan is most likely doing the following.

   Riding down the hill: ______________________________

   Walking her bike back up the hill: ______________________________

2. To find the average speed from a distance-time graph, calculate the slope of the line. You can find the slope of a line with the following formula:

$$\text{slope of a line} = \frac{(y_2 - y_1)}{(x_2 - x_1)}, \text{ or } \frac{\text{distance traveled}}{\text{time interval}}$$

   Find Joan's average speed, in kilometers per minute, for the following.

   Her greatest average speed: ______________________________

   The entire trip: ______________________________

3. On a distance-time graph, what kind of slope represents an object that has stopped moving entirely? (Give both a description and a numerical answer.)

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4. Suppose you want to make a graph showing Joan's distance from her home. How could you change the *y*-axis of the graph to show this information?

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NJ ASK Practice

1. Which of the following is an example of a contact force?

   A. electricity
   B. friction
   C. gravity
   D. magnetism

2. In which situation are the forces acting on the object balanced?

   A. A car turns a corner at a constant speed.
   B. A minivan slows as it approaches a stoplight.
   C. A hot-air balloon rises at a constant speed.
   D. A skateboarder picks up speed as she skates down a hill.

3. The net force acting on an object is 0 N. Which of the following best describes the motion of the object?

   A. The object is not moving.
   B. The object is moving in a straight line at a constant speed.
   C. The object is slowing down.
   D. The object's motion is not changing.

4. Sean pushes a parked car with a force of 80 newtons (N). The car does not move. Which of the following best describes the force that the car exerts on Sean?

   A. the same amount of force as Sean exerts
   B. less force than Sean exerts
   C. no force
   D. more force than Sean exerts

5. Which force has the greatest influence on the structure of solar systems and galaxies?

   A. electricity
   B. friction
   C. gravity
   D. magnetism

6. Zack throws a ball straight up into the air. The height of the ball at different times is shown in the table below.

Zack's Ball Toss

Time (s)	Height (m)
0	0
1	15
2	20
3	15
4	0

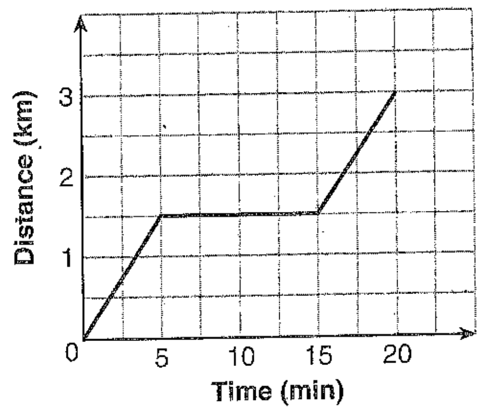
What is the average speed of the ball from 3 s to 4 s?

A. 5 m/s
B. 8 m/s
C. 12 m/s
D. 15 m/s

7. In outer space, a small ball of rock and ice travels for thousands of years. Its motion does not change in any way during that time. As it approaches the solar system, however, it comes under the influence of the Sun's gravity, and its motion begins to change. Which principle does this demonstrate?

A. Every action has an equal and opposite reaction.
B. An object in motion moves in a straight line at constant speed until acted on by a net force.
C. Matter may change form but not be created or destroyed.
D. In nature, favorable traits tend to aid in survival and reproduction.

Tamara's Bike Ride



8. Tamara rode her bicycle to her friend's house. The distance-time graph shown above represents Tamara's trip. Describe Tamara's speed and the net force acting on her bicycle between 15 min and 20 min. Include the proper units.