Section 2

Friction and Gravity

Reading Preview

Key Concepts

- What factors determine the strength of the friction force between two surfaces?
- What factors affect the gravitational force between two objects?
- Why do objects accelerate during free fall?

Key Terms

- friction • static friction
- sliding friction
- rolling friction • fluid friction
- gravity • mass • weight
- free fall • air resistance
- terminal velocity • projectile

Target Reading Skill

Comparing and Contrasting As you read, compare and contrast friction and gravity by completing a table like the one below.

	Friction	Gravity
Effect on motion	Opposes motion	
Depends on		
Measured in		

Lab zone Discover Activity

Which Lands First?

1. Stack three quarters. Place tape between the quarters to hold them tightly together. Place the stack of quarters next to a single quarter near the edge of a desk.
2. Put a ruler flat on the desk behind the coins. Line it up parallel to the edge of the desk and just touching the coins.
3. Keeping the ruler parallel to the edge of the desk, push the coins over the edge at the same time. Observe how long the coins take to land.

Think It Over

Predicting Did you see a difference in the time the coins took to fall? Use what you observed to predict whether a soccer ball will fall more quickly than a marble. Will a pencil fall more quickly than a book? How can you test your predictions?

What happens when you jump on a sled on the side of a snow-covered hill? Without actually doing this, you can predict that the sled will slide down the hill. Now think about what happens at the bottom of the hill. Does the sled keep sliding? Again, without actually riding the sled, you can predict that the sled will slow down and stop.

Why does the sled's motion change on the side of the hill and then again at the bottom? In each case, unbalanced forces act on the sled. The force of gravity causes the sled to accelerate down the hill. The force of friction eventually causes the sled to stop. These two forces affect many motions on Earth.

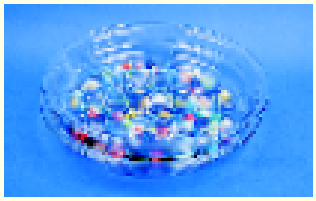
◀ Friction and gravity both act on the sled.

Lab zone **Try This Activity**

Spinning Plates

You can compare rolling friction to sliding friction.

1. Stack two identical pie plates together. Try to spin the top plate.
2. Now separate the plates and fill the bottom of one pie plate loosely with marbles.



3. Place the second plate in the plate with marbles.
4. Try to spin the top plate again. Observe the results.

Drawing Conclusions What applications can you think of for the rolling friction modeled in this activity?

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Static Friction Four types of friction are shown in Figure 6. The friction that acts on objects that are not moving is called **static friction.** Because of static friction, you must use extra force to start the motion of stationary objects. For example, think about what happens when you try to push a heavy desk across a floor. If you push on the desk with a force less than the force of static friction between the desk and the floor, the desk will not move. To make the desk move, you must exert a force greater than the force of static friction. Once the desk is moving, there is no longer any static friction. However, there is another type of friction—sliding friction.

Sliding Friction **Sliding friction** occurs when two solid surfaces slide over each other. Sliding friction can be useful. For example, you can spread sand on an icy path to improve your footing. Ballet dancers apply a sticky powder to the soles of their ballet slippers so they won't slip on the dance floor. And when you stop a bicycle with hand brakes, rubber pads slide against the tire surfaces, causing the wheels to slow and eventually stop. On the other hand, sliding friction is a problem if you fall off your bike and skin your knee!

Rolling Friction When an object rolls across a surface, **rolling friction** occurs. Rolling friction is easier to overcome than sliding friction for similar materials. This type of friction is important to engineers who design certain products. For example, skates, skateboards, and bicycles need wheels that move freely. So engineers use ball bearings to reduce the friction between the wheels and the rest of the product. These ball bearings are small, smooth steel balls that reduce friction by rolling between moving parts.

Fluid Friction Fluids, such as water, oil, or air, are materials that flow easily. **Fluid friction** occurs when a solid object moves through a fluid. Like rolling friction, fluid friction is easier to overcome than sliding friction. This is why the parts of machines that must slide over each other are often bathed in oil. In this way, the solid parts move through the fluid instead of sliding against each other. When you ride a bike, fluid friction occurs between you and the air. Cyclists often wear streamlined helmets and specially designed clothing to reduce fluid friction.

Reading Checkpoint **What are two ways in which friction can be useful?**

Lab zone **Try This Activity**

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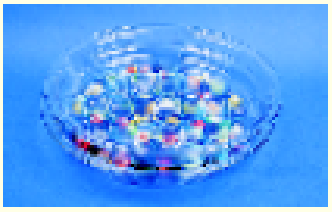

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Reading Checkpoint **What are two ways in which friction can be useful?**

FIGURE 6

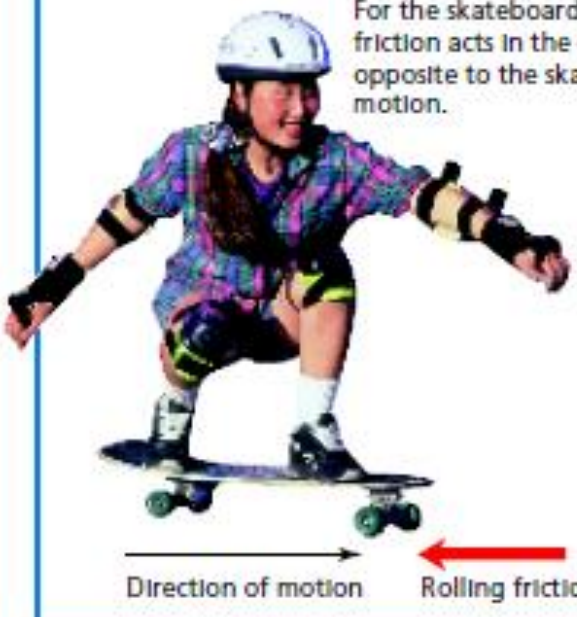
Types of Friction

Types of friction include static, sliding, rolling, and fluid friction. **Making Generalizations** *In what direction does friction act compared to an object's motion?*

Static Friction ▼
To make the sled move, the athlete first has to overcome the force of static friction. Static friction acts in the opposite direction to the intended motion.

Sliding Friction ▲
Once the sled is moving, it slides over the floor. Sliding friction acts between the sled and the floor in the opposite direction to the sled's motion.

Rolling Friction ▼
Rolling friction occurs when an object rolls over a surface. For the skateboarder, rolling friction acts in the direction opposite to the skateboard's motion.



Fluid Friction ▲
When an object pushes fluid aside, friction occurs. The surfer must overcome the fluid friction of the water.

FIGURE 7
Gravity and Acceleration
Divers begin accelerating as soon as they leap from the platform.

Gravity

Would you be surprised if you let go of a pen you were holding and it did not fall? You are so used to objects falling that you may not have thought about why they fall. One person who thought about it was Isaac Newton. He concluded that a force acts to pull objects straight down toward the center of Earth. **Gravity** is a force that pulls objects toward each other.

Universal Gravitation Newton realized that gravity acts everywhere in the universe, not just on Earth. It is the force that makes an apple fall to the ground. It is the force that keeps the moon orbiting around Earth. It is the force that keeps all the planets in our solar system orbiting around the sun.

What Newton realized is now called the law of universal gravitation. The law of universal gravitation states that the force of gravity acts between all objects in the universe. This means that any two objects in the universe, without exception, attract each other. You are attracted not only to Earth but also to all the other objects around you. Earth and the objects around you are attracted to you as well. However, you do not notice the attraction among objects because these forces are small compared to the force of Earth's attraction.

Factors Affecting Gravity **Two factors affect the gravitational attraction between objects: mass and distance. Mass** is a measure of the amount of matter in an object. The SI unit of mass is the kilogram. One kilogram is the mass of about 400 modern pennies. Everything that has mass is made up of matter.

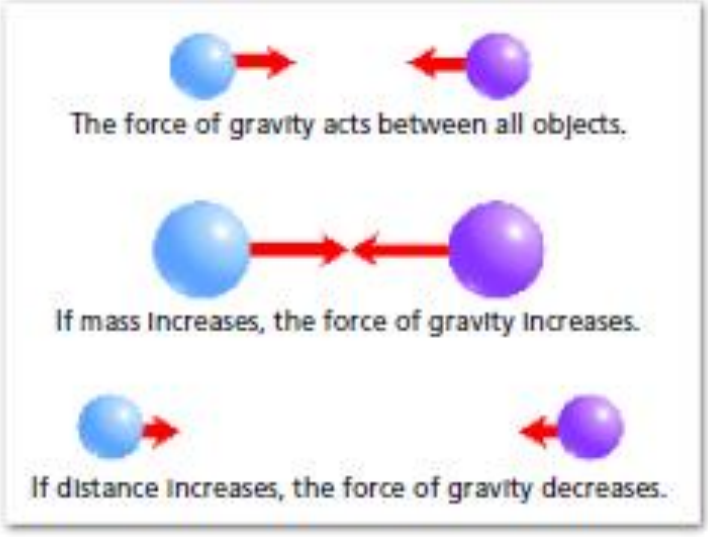


FIGURE 8
Gravitational Attraction
Gravity increases with mass and decreases with distance. Inferring *The sun's mass is about 300,000 times greater than Earth's mass, yet the moon orbits around Earth, not the sun. Why?*

The more mass an object has, the greater its gravitational force. Because the sun's mass is so great, it exerts a large gravitational force on the planets. That's one reason why the planets orbit the sun.

In addition to mass, gravitational force depends on the distance between the objects. The farther apart two objects are, the lesser the gravitational force between them. For a spacecraft traveling toward Mars, Earth's gravitational pull decreases as the spacecraft's distance from Earth increases. Eventually the gravitational pull of Mars becomes greater than Earth's, and the spacecraft is more attracted toward Mars.

Weight and Mass Mass is sometimes confused with weight. Mass is a measure of the amount of matter in an object; weight is a measure of the gravitational force exerted on an object. The force of gravity on a person or object at the surface of a planet is known as **weight.** So, when you step on a bathroom scale, you are determining the gravitational force Earth is exerting on you.

Weight varies with the strength of the gravitational force but mass does not. Suppose you weighed yourself on Earth to be 450 newtons. Then you traveled to the moon and weighed yourself again. You might be surprised to find out that you weigh only about 75 newtons—the weight of about 8 kilograms on Earth! You weigh less on the moon because the moon's mass is only a fraction of Earth's.

Reading Checkpoint **What is the difference between weight and mass?**

Lab zone **Skills Activity**

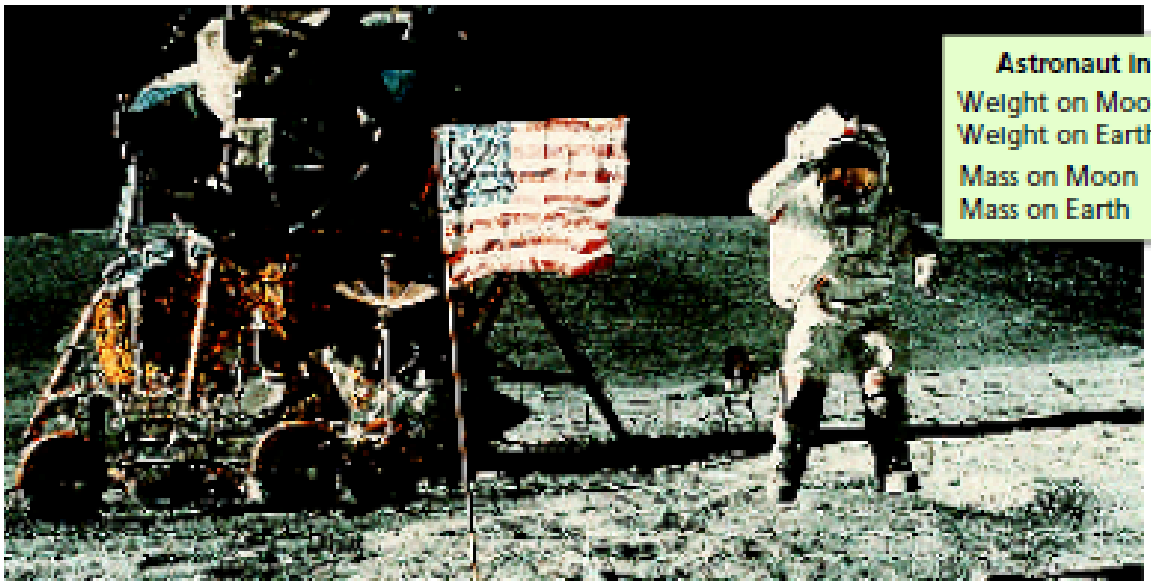
Calculating

You can determine the weight of an object if you measure its mass.

1. Estimate the weight of four objects. (*Hint:* A small lemon weighs about 1 N.)
2. Use a balance to find the mass of each object. If the measurements are not in kilograms, convert them to kilograms.
3. Multiply each mass by 9.8 m/s^2 to find the weight in newtons.

How close to actual values were your estimates?

FIGURE 9
Mass and Weight This astronaut jumps easily on the moon. Comparing and Contrasting *How do his mass and weight on the moon compare to his mass and weight on Earth?*



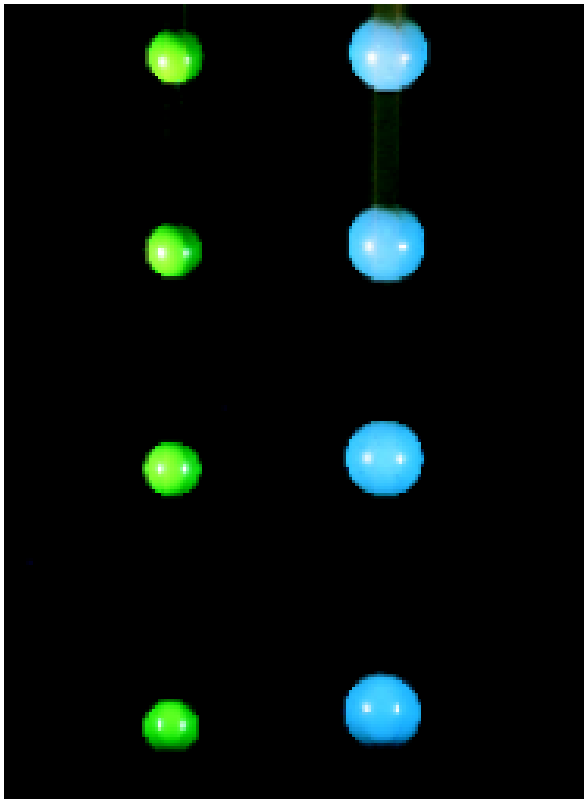


FIGURE 10
Free Fall
In the absence of air, two objects with different masses fall at exactly the same rate.

Gravity and Motion

On Earth, gravity is a downward force that affects all objects. When you hold a book, you exert a force that balances the force of gravity. When you let go of the book, gravity becomes an unbalanced force and the book falls.

Free Fall When the only force acting on a falling object is gravity, the object is said to be in **free fall.** An object in free fall accelerates as it falls. Do you know why? **In free fall, the force of gravity is an unbalanced force that causes an object to accelerate.**

How much do objects accelerate as they fall? Near the surface of Earth, the acceleration due to gravity is 9.8 m/s^2. This means that for every second an object is falling, its velocity increases by 9.8 m/s. For example, suppose an object is dropped from the top of a building. Its starting velocity is 0 m/s. After one second, its velocity has increased to 9.8 m/s. After two seconds, its velocity is 19.6 m/s (9.8 m/s + 9.8 m/s). The velocity continues to increase as the object falls.

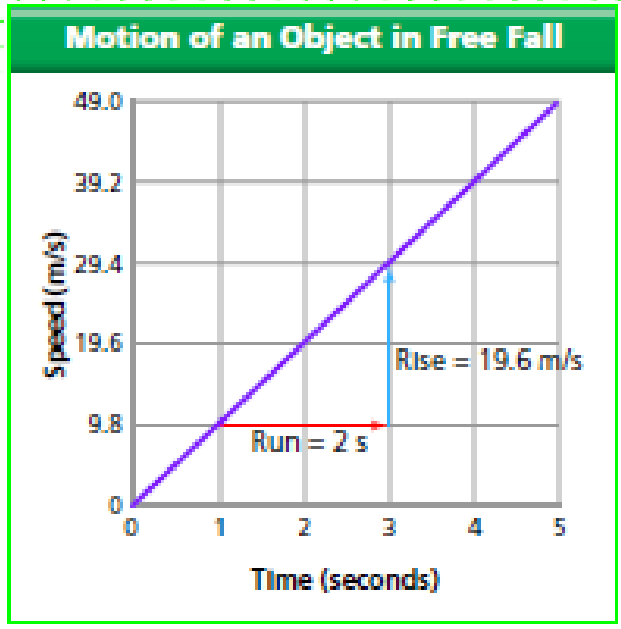
While it may seem hard to believe at first, all objects in free fall accelerate at the same rate regardless of their masses. The two falling objects in Figure 10 demonstrate this principle.

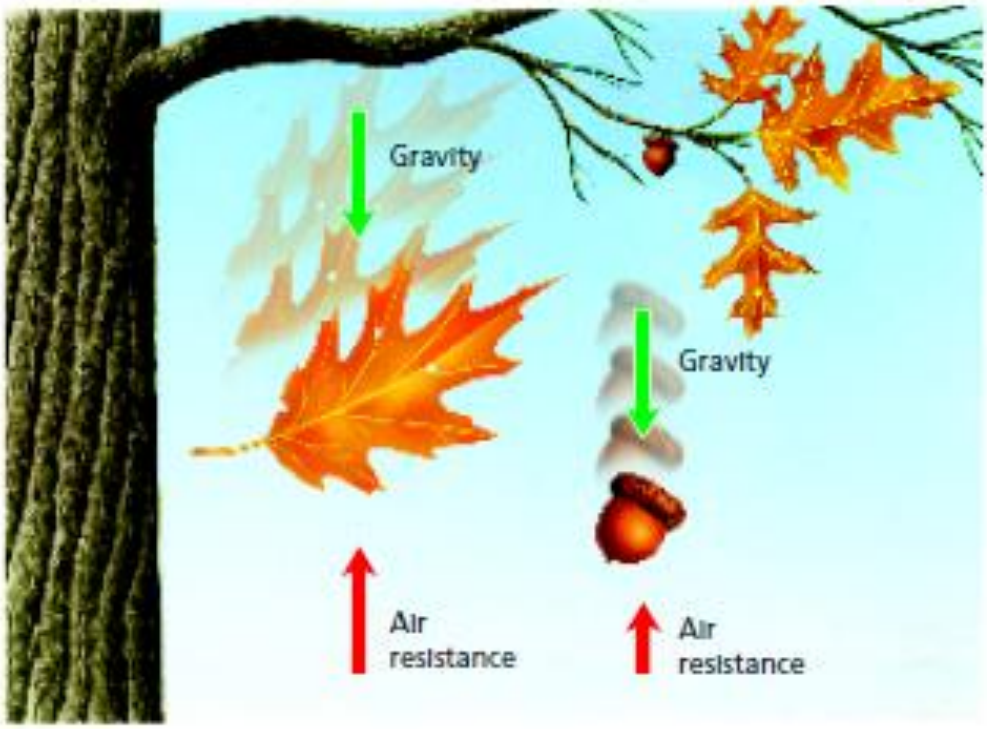
Math Analyzing Data

Free Fall

Use the graph to answer the following questions.

1. **Interpreting Graphs** What variable is on the horizontal axis? The vertical axis?
2. **Calculating** Calculate the slope of the graph. What does the slope tell you about the object's motion?
3. **Predicting** What will be the speed of the object at 6 seconds?
4. **Drawing Conclusions** Suppose another object of the same size but with a greater mass was dropped instead. How would the speed values change?





Air Resistance Despite the fact that all objects are supposed to fall at the same rate, you know that this is not always the case. For example, an oak leaf flutters slowly to the ground, while an acorn drops straight down. Objects falling through air experience a type of fluid friction called **air resistance.** Remember that friction is in the direction opposite to motion, so air resistance is an upward force exerted on falling objects. Air resistance is not the same for all objects. Falling objects with a greater surface area experience more air resistance. That is why a leaf falls more slowly than an acorn. In a vacuum, where there is no air, all objects fall with exactly the same rate of acceleration.

You can see the effect of air resistance if you drop a flat piece of paper and a crumpled piece of paper at the same time. Since the flat paper has a greater surface area, it experiences greater air resistance and falls more slowly. In a vacuum, both pieces of paper would fall at the same rate.

Air resistance increases with velocity. As a falling object speeds up, the force of air resistance becomes greater and greater. Eventually, a falling object will fall fast enough that the upward force of air resistance becomes equal to the downward force of gravity acting on the object. At this point the forces on the object are balanced. Remember that when forces are balanced, there is no acceleration. The object continues to fall, but its velocity remains constant. The greatest velocity a falling object reaches is called its **terminal velocity.** Terminal velocity is reached when the force of air resistance equals the weight of the object.

FIGURE 11
Air Resistance
Falling objects with a greater surface area experience more air resistance. In a vacuum, there is no air resistance. **Comparing and Contrasting** *Which object will hit the ground first when the leaf and acorn fall from the tree? When they fall in a tube without air?*

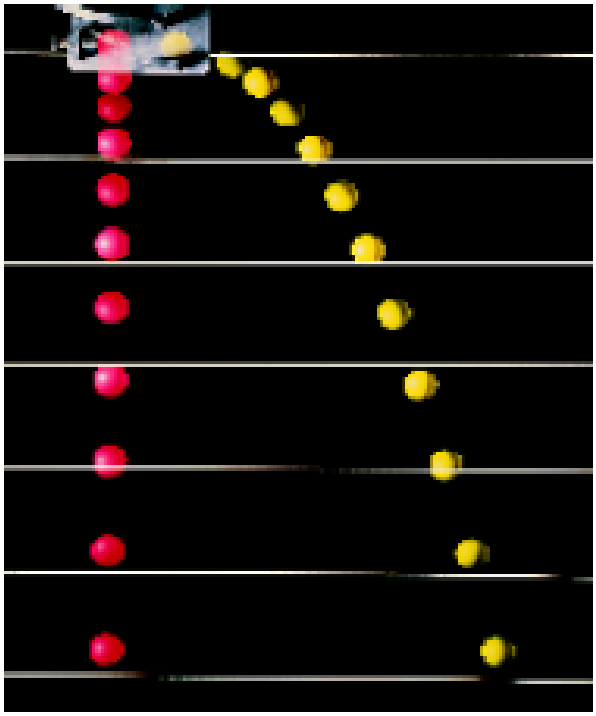


Figure 12
Projectile Motion
One ball is dropped vertically and a second ball is thrown horizontally at the same time. Making Generalizations *Does the horizontal velocity of the ball affect how fast it falls?*

Projectile Motion Rather than dropping a ball straight down, what happens if you throw it horizontally? An object that is thrown is called a **projectile** (pruh JEK tul). Will a projectile that is thrown horizontally land on the ground at the same time as an object that is dropped?

Look at Figure 12. The yellow ball was given a horizontal push at the same time as the red ball was dropped. Even though the yellow ball moves horizontally, the force of gravity continues to act on it in the same way it acts on the red ball. The yellow ball falls at the same rate as the red ball. Thus, both balls will hit the ground at exactly the same time.

In a similar way, an arrow flying toward a target is a projectile. Because of the force of gravity, the arrow will fall as it flies toward the target. So if you try to hit the bull's-eye, you must aim above it to account for gravity's pull. When you throw a projectile at an upward angle, the force of gravity reduces its vertical velocity. Eventually, the upward motion of the projectile will stop, and gravity will pull it back toward the ground. From this point, the projectile will fall at the same rate as any dropped object.

Reading Checkpoint **How does gravity affect objects that are moving horizontally?**

Section 2 Assessment

Target Reading Skill

Comparing and Contrasting Use the information in your table about friction and gravity to help you answer the questions below.

Reviewing Key Concepts

1. a. Listing What are the four types of friction?
   b. Summarizing What factors affect the friction force between two surfaces?
   c. Classifying What types of friction occur when you ride a bike through a puddle?
2. a. Identifying What is the law of universal gravitation?
   b. Explaining How do mass and distance affect the gravitational attraction between objects?
   c. Predicting What would happen to your weight on the surface of a planet whose mass was many times greater than Earth's? Why?
3. a. Reviewing Why does an object accelerate when it falls toward Earth's surface?
   b. Describing How does the mass of an object affect its acceleration during free fall?
   c. Applying Concepts What force changes when a sky diver's parachute opens? What force stays the same?

Writing in Science

Cause-and-Effect Paragraph Suppose Earth's gravitational force were decreased by half. How would this change affect a game of basketball? Write a paragraph explaining how the motion of the players and the ball would be different.