Lesson 3 | Newton's Second Law

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Inquiry **Launch Lab** **LESSON 3: 10 minutes**

What forces affect motion along a curved path?

When traveling in a car or riding on a roller coaster, you can feel different forces acting on you as you move along a curved path. What are these forces? How do they affect your motion?

Procedure

1. Read and complete a lab safety form.
2. Attach a piece of **string** about 1 m long to a rolled-up **sock.**

   WARNING: Find a spot away from your classmates for the next steps.
3. While holding the end of the string, swing the sock around in a circle above your head. Notice the force tugging on the string.
4. Repeat step 3 with two socks rolled together. In the Data and Observations section below, compare the force of swinging one sock to the force of swinging two socks.

Data and Observations

Think About This

1. **Describe** the forces acting along the string while you were swinging it. Classify each force as balanced or unbalanced.

   ____

   ____

   ____

2. **Key Concept** How does the force from the string seem to affect the sock's motion?

   ____

   ____

   ____

Content Vocabulary

LESSON 3

Newton's Second Law

Directions: *Answer each question on the lines provided. Use complete sentences.*

centripetal force **circular motion** **Newton's second law of motion**

1. How is centripetal force related to circular motion?

____

____

____

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2. What is Newton's second law of motion?

____

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3. What is the equation for Newton's second law?

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4. What is one example of an object that is affected by centripetal force?

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Lesson Outline **LESSON 3**

Newton's Second Law

A. How do forces change motion?

1. Forces change an object's motion by changing its ____________________, its ____________________, or both.

2. Only ____________________ forces can change the velocity of an object.

3. You know unbalanced forces are acting on an object that is at rest when the object starts ____________________.

4. Unbalanced forces change the ____________________ of a moving object.

a. If a net force acts on a moving object in the direction that the object is moving, the object will ____________________.

b. If a net force acts on a moving object in the direction that is opposite to the direction that the object moves, the object ____________________.

c. Another way unbalanced forces can change the velocity of a moving object is to change the ____________________ of the object's motion.

5. The force of gravity acts on a ball that is thrown by changing the direction of the ball, pulling it ____________________.

6. Another name for change in velocity over time is ____________________.

7. Unbalanced forces can make an object accelerate by changing the object's ____________________, ____________________, or both.

B. Newton's Second Law of Motion

1. According to ____________________, the acceleration of an object is equal to the net force acting on the object divided by the object's mass.

2. The direction of acceleration is the same as the direction of the ____________________.

3. The units for Newton's second law are SI units—force is measured in ____________________; mass is measured in ____________________; acceleration is measured in ____________________.

4. One newton is the same as one ____________________.

Lesson Outline continued

C. Circular Motion

1. ____________________ is any motion in which an object is moving in a curved path.
2. ____________________ causes objects to tend to move along a straight path.
3. In circular motion, a force that acts perpendicular to the direction of motion toward the center of the circle is called a(n) ____________________.
4. An object that is moving in a curve accelerates in the ____________________ of the centripetal force.
5. Any object that circles a larger object is called a(n) ____________________.
    - **a.** Satellites move in a circle because a(n) ____________________ acts on them.
    - **b.** ____________________ is the centripetal force that acts on satellites by continuously changing their direction of motion; this results in ____________________ motion.
6. Earth's ____________________ keeps the Moon in orbit around Earth.
7. The planets remain in orbit because the ____________________ gravity pulls on them.

Inquiry **MiniLab** **LESSON 3: 10 minutes**

How are force and mass related?

Unbalanced forces cause an object to accelerate. If the mass of the object increases, how does the force required to accelerate the object change?

Procedure

1. Read and complete a lab safety form.
2. Tie a **string** to a **small box.** Pull the box about 2 m across the floor. Notice the force required to cause the box to accelerate.
3. Put **clay** in the box to increase its mass. Pull the box so that its acceleration is about the same as before. Notice the force required.

Analyze and Conclude

1. **Compare** the strength of the force needed to accelerate the box each time.

____

____

____

2. **Key Concept** How did the mass affect the force needed to accelerate the box?

____

____

____

Content Practice A **LESSON 3**

Newton's Second Law

Directions: *On each line, write the term from the word bank that correctly completes each sentence. Each term is used only once.*

acceleration	**center**	**centripetal force**	**direction**	**gravity**
inertia	**mass**	**newton**	**speed**	**straight**

1. An object's velocity can be changed by changing its ______________, its ______________, or both.

2. A change in velocity over time is called ______________.

3. The increasing speed of a falling object is caused by ______________.

4. One kg•m/s^2 can also be expressed as 1 ______________.

5. Newton's second law of motion describes acceleration as force divided by ______________.

6. Because of ______________, an object in circular motion has a tendency to move away in a(n) ______________ line.

7. The force that pulls an object in circular motion and keeps it in circular motion is ______________.

8. The direction of the force that pulls an object in circular motion is toward the ______________ of the circle.

Content Practice B **LESSON 3**

Newton's Second Law

Directions: *This diagram represents two objects above Earth, the center of which is marked with a dot. Object 1 is a satellite orbiting Earth in the direction shown by the arrow. Object 2 is an object headed toward Earth. Use the diagram to respond to the statement.*

1. Add three arrows to the drawing—one showing the direction of the satellite's acceleration (label it line A), one showing the path the satellite would take if it suddenly became free of Earth's gravitation (label it line B), and a third showing the direction of object 2's acceleration (label it line C).

Directions: *On the line before each question or statement, write the letter of the correct answer.*

_______ **2.** If a force acts on a moving object in the same direction that the object is moving, what will happen to the object?
A. It will stop.
B. It will speed up.
C. It will slow down.
D. It will continue moving at the same speed.

_______ **3.** After a baseball leaves the pitcher's hand, what is the main force acting on it?
A. gravity
B. friction
C. electric force
D. centripetal force

_______ **4.** Newton's second law of motion states that force is equal to mass times
A. weight.
B. inertia.
C. velocity.
D. acceleration.

Word-Usage Activity: Understanding Words with Multiple Meanings

Some words such as *force* have more than one meaning:

A. *n.* group of people combined for joint action

B. *n.* act of physically restraining someone or something

C. *n.* power to convince

D. *n.* influence on an object that produces a change in motion

E. *v.* to compel someone to do something

F. *v.* to break open or into

Directions: *On the line, write the letter of the definition for the term* force *that is used in each sentence.*

_______ **1.** At Monday's meeting, the citizens had to force city council to discuss the parking issue.

_______ **2.** Our town's force of firefighters works to fight fires and to help prevent them.

_______ **3.** By the force of her argument, the trial lawyer convinced the jury that her client was innocent.

_______ **4.** Because the door was locked, the rescue worker had to force his way into the room.

_______ **5.** The force of the guards kept the prisoners from escaping.

_______ **6.** The force of gravity causes the Moon to orbit Earth.

Language-Usage Activity: Simple Present Tense

The simple present tense is used for communication concerning actions and events that occur in the present time. You use the simple present tense for actions or events that are not continuous and to express ideas that are generally accepted to be true.

We *discuss* science in our study group.

South America *is* one of the world's continents.

She *enjoys* reading about the history of science.

The simple present tense for singular verbs is usually formed by adding an −*s* ending to the base verb (V): (V + −*s*).

The textbook *covers* more than 1,500 years of scientific discoveries.

The simple present tense for plural verbs is formed by using the base form of the verb (V).

The classes *study* one chapter per week.

Directions: *Circle the correct form of the verbs in each sentence below. Use the words in context to help you decide which verb tense fits best.*

1. When unbalanced forces (act/acts) on an object that is not moving, the object (accelerate/accelerates) in the direction of the net force.

2. If the net force (is/are) in the same direction as the object's motion, the object (go/goes) faster.

3. When a moving object (respond/responds) to a force, its motion (depend/depends) on the direction the object is moving and the direction in which the force is applied.

4. However, if the net force (push/pushes) in the opposite direction than the object is moving, the object (slow/slows) down.

5. When an unbalanced force (act/acts) on a moving object, the motion of the object (change/changes).

Newton's Second Law Equation

Newton's second law of motion states that the acceleration of an object equals the net force on the object divided by the object's mass. This can be shown by the equation below, where a = acceleration (in m/s^2), F = net force (N), and m = mass (in kg).

$$a = \frac{F}{m}$$

You can rearrange the equation to solve for force or mass.

$$F = m \times a \qquad m = \frac{F}{a}$$

If a **4.5**-kg bowling ball is rolled down the bowling lane with a force of **15** N, what is the acceleration of the ball?

Step 1 Identify the variable you will solve for and choose the appropriate equation.
You are solving for a, the acceleration.

$$a = \frac{F}{m}$$

Step 2 Substitute the known values to solve the equation.

$$a = \frac{\mathbf{15}\text{ N}}{\mathbf{4.5}\text{ kg}}$$

$$a = \mathbf{3.3}\text{ m/s}^2$$

Practice

1. If a 6-kg bowling ball is rolled down the bowling lane with a force of 12 N, what is the acceleration of the ball?

2. If a 16-N net force makes an object accelerate at 8 m/s^2, what is the mass of the object?

3. A 25-N net force is applied to a rolling cart and produces an acceleration of 5 m/s^2. What is the cart's mass?

4. A 0.5-kg ball accelerated at 50 m/s^2. What force was applied?

Name ______________________ Date ______________ Class __________

School to Home

LESSON 3

Newton's Second Law

Did you know?

Just a year after Isaac Newton was awarded a scholarship to Cambridge University, the plague forced the school to close. Newton returned home, but made many of his discoveries related to gravity, optics, and mathematics during this period.

For this activity, you will need a piece of chalk, a golf ball and a table tennis ball (or two other balls that are similar in size but different in mass), a straightedge, and a measuring tape.

1. Set up the activity outside on a level sidewalk or driveway. Mark a line on the driveway or sidewalk. During the activity, you will move balls from the line.

2. Start with the lighter ball. Set it on the line and strike the ball with the flat side of the straightedge. You will strike the second, heavier ball with the same force, so practice a few times to be sure you strike the ball from the same distance and with the same force. Measure the distance the ball traveled. Record it here.

____

3. Repeat Step 2 with the heavier ball. Record the distance the ball moved here.

____

4. **Recall** Newton's second law of motion. What does it state?

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____

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5. Does the activity demonstrate Newton's second law? Explain.

____

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____

Name ______________________ Date ______________ Class ________

Key Concept Builder

LESSON 3

Newton's Second Law

Key Concept What is Newton's second law of motion?

Newton's second law of motion describes the relationship between an object's change in velocity over time, or acceleration, and unbalanced forces exerted on the object. To change an object's velocity, unbalanced forces must change the object's speed, direction, or both.

Directions: *On the line before each item, write* S *if it describes a change of speed,* D *if it describes a change of direction, or* B *if it describes a change of both factors.*

_______ **1.** a car braking at a traffic light

_______ **2.** a child on a merry-go-round as it starts up

_______ **3.** a child on a merry-go-round in mid cycle

_______ **4.** an ice skater making a jump

_______ **5.** an elevator beginning to descend

_______ **6.** a ball dropped from waist height

_______ **7.** a bouncing ball

_______ **8.** the tip of a spinning fan blade

_______ **9.** a moving sewing-machine needle

_______ **10.** a swinging pendulum

Key Concept Builder

Newton's Second Law

Key Concept What is Newton's second law of motion?

Newton's second law of motion describes the relationship between an object's change in velocity over time, or acceleration, and unbalanced forces exerted on the object. Often, gravity is the dominant force affecting an object's velocity.

Directions: *Put a check mark on the line before each example in which gravity is the main force influencing the object's velocity.*

_______ **1.** a spaceship blasting off

_______ **2.** a spaceship in orbit

_______ **3.** a pitched ball on the way to the plate

_______ **4.** a dropped ball

_______ **5.** a comet moving around the Sun

_______ **6.** the rotation of Earth

_______ **7.** the movement of the tides

_______ **8.** a rock sinking to the bottom of a lake

_______ **9.** windmill blades turning

_______ **10.** a rock formation collapsing

Name ______________________ Date ______________ Class ________

Key Concept Builder

LESSON 3

Newton's Second Law

Key Concept What is Newton's second law of motion?

Newton's Second Law Equation

$$\text{Acceleration (in m/s}^2) = \frac{\text{net force (in N)}}{\text{mass (in kg)}}$$

$$a = \frac{F}{m}$$

$$F = m \times a$$

$$m = \frac{F}{a}$$

Directions: *Use the equation to answer each question.*

1. A boy throws a 1-kg rock with a force of 5 N. What is the acceleration of the rock when he lets go of it?

____

2. A toy boat accelerates through calm water at 2.5 m/s^2 powered by a motor exerting a net force of 5 N. What is the mass of the boat?

____

3. A net force pushing a 15-kg wagon on a level road results in an acceleration of 2 m/s^2. What is the net force?

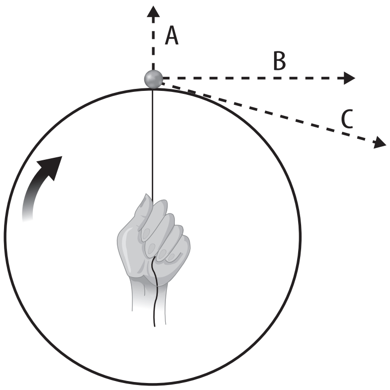
____

Name ______________________ Date ______________ Class ________

Key Concept Builder **LESSON 3**

Newton's Second Law

Key Concept How does centripetal force affect circular motion?



Directions: *The diagram shows a ball on a string being swung around in a circle. Use the diagram to answer each question.*

1. What force keeps the ball moving in a circle?

____

2. What is producing this force?

____

3. Why is the ball accelerating?

____

____

4. In which direction is it accelerating?

____

5. If the ball broke away from the string at the position shown, would it move away on line A, B, or C?

____

6. What causes it to take this path?

____

7. After breaking away from the string, what is the main force that would be acting on the ball?

____

Finding Neptune

Isaac Newton's writings were the result of observing nature and attempting to explain its behavior in terms of the consequences of a few principles (or laws), expressed as mathematical relationships. In 1687, Newton published a book often referred to as the *Principia*. Many consider its publication the beginning of modern science. The *Principia* inspired scientific theory and discoveries for the next 200 years.

Predicting a New Planet

Newton explained the motions of objects on Earth, the motion of objects in the heavens, the tides, and more, with a single principle that we now call Newton's second law. The idea that forces can change an object's motion by changing its speed and/or direction was at the core of an investigation of the motions of the planet Uranus in the 1800s.

In the 1820s, astronomers had enough accurate data on the motion of Uranus to notice that it did not move according to predictions calculated from Newton's law. In 1841, John Couch Adams, a student at Cambridge University, had the idea that Uranus was in fact following Newton's law, but its motion and direction were affected by the force from all the known planets as well as a force from an unseen planet. Adams wrote: "Formed a design . . . this week, of investigating, as soon as possible after taking my degree, the irregularities of the motion of Uranus, which are yet unaccounted for; in order to find out whether they may be attributed to the action of an undiscovered planet beyond it."

Finding a Planet

Meanwhile, other people got involved.

June 1845: The director of the Paris Observatory asked Urbain-Jean-Joseph Leverrier to work on the problem of Uranus's orbit.

October 1845: Adams had deduced an orbit, mass, and position for the perturbing planet. Neither Adams nor Leverrier knew that the other was working on the problem.

June 1846: Leverrier published a paper in which he stated that the only possible explanation for the orbit of Uranus is the existence of a planet farther from the Sun than Uranus.

June 1846: The results of Leverrier's paper reached the Astronomer Royal in Britain, who saw that Leverrier's and Adams's prediction for the position of the new planet were almost identical.

September 1846: Leverrier asked the German astronomer J. G. Galle at the Royal Observatory in Berlin to search for the "new planet" at his predicted location. Galle located it within 30 minutes.

Applying Critical-Thinking Skills

Directions: *Respond to each statement.*

1. **Identify** the force from the known planets, as well as the unknown one, that was affecting the position and motion of Uranus.

2. Galle confirmed that he had discovered the "new planet" by observing it again the following night. **Explain** how a second observation about the object's position would confirm that the object was a planet.

Where is the Moon?

In this activity, you will observe, from the same location for a series of nights, the motion of the Moon in relation to Earth.

Observe and Record

1. **Construct** a 30-day calendar that begins with the day that you will start this activity. Each day should have a box large enough for a drawing of the Moon.

2. Beginning with the first day on the calendar, and on every third day for the rest of the month, do the following:
   - At the same time every evening, stand outside in the same place, and determine where the Moon is in the sky.
   - **Draw** a diagram that shows where you are standing relative to the horizon and at approximately what angle the position of the Moon is in relation to where you are.
   - **Draw** a diagram of the phase of the Moon for your calendar.

3. At the end of the month, use the data that you gathered to draw a diagram of the Sun, Earth, and the Moon over the 30-day period. Use Newton's law of motion to explain why the Moon continues to move around Earth.

Name ______________________________ Date ______________ Class ________

Inquiry **Skill Practice** *Use Variables* **LESSON 3: 25 minutes**

How does a change in mass or force affect acceleration?

Force, mass, and acceleration are all related variables. In this activity, you will use these variables to study Newton's second law of motion.

Learn It

Vary means "to change." A **variable** is a quantity that can be changed. For example, the variables related to Newton's second law of motion are force, mass, and acceleration. You can find the relationship between any two of these variables by changing one of them and keeping the third variable the same.

Try It

1. Read and complete a lab safety form.
2. Hold a **baseball** in one hand and a **foam ball** in your other hand. Compare the masses of the two balls.
3. Lay both balls on a flat surface. Push a **meterstick** against the balls at the same time with the same force. Compare the accelerations of the balls.
4. Using only the baseball and the meterstick, lightly push the ball and observe its acceleration. Again observe the acceleration as you push the baseball with a stronger push. Compare the accelerations of the ball when you used a weak force and when you used a strong force.

Apply It

5. Answer the following questions for both step 3 and step 4. What variable did you change? What variable changed as a result? What variable did you keep the same?

____

____

6. Using your results, state the relationship between acceleration and mass if the net force on an object does not change. Then, state the relationship between acceleration and force if mass does not change.

____

____

____

7. **Key Concept** How do your results support Newton's second law of motion?

____

____