Collisions between Objects

Percussionists use collisions to make music.

By the end of this lesson . . .

you will be able to apply Newton's laws of motion to design a solution to a problem involving two colliding objects.

Go online to view the digital version of the Hands-On Lab for this lesson and to download additional lab resources.

CAN YOU EXPLAIN IT?

How can Newton's laws be applied to protect a smartphone screen during a collision?

People carry smartphones everywhere. If people are not careful, they can drop or bump their smartphones into other objects. Smartphones may be damaged in a collision.

1. Oh no! Have you ever seen this problem with a smartphone or a tablet? Write a step-by-step account of what you think might have happened to cause damage to the smartphone pictured.

EVIDENCE NOTEBOOK As you work through the lesson, record evidence that helps you determine how to protect a smartphone screen during a collision.

Applying Newton's Laws to Collisions

Collisions between objects happen every day. A collision may be as simple as a ball bouncing on the ground. Other collisions, such as car crashes, may involve many objects and multiple collisions. These complex collisions may be more difficult to analyze than simple collisions. The motion of each object in a collision can be described by Newton's laws of motion.

2. Discuss Over the years, many meteoroids have collided with Earth. Many of these collisions occurred long ago, and the craters have been changed due to weathering. Look at the shape of Meteor Crater. What information does the crater's shape give you about the collision? What do you think happened to life in the area after the impact?

Meteor Crater in Arizona is one of the best preserved impact sites on Earth. The crater is almost 1 mile across and 240 feet deep. It was formed approximately 50,000 years ago.

Newton's Third Law of Motion and Collisions

When two objects collide, each object pushes the other. Think about hitting a softball with a bat. The bat collides with the ball and pushes it away. The ball also exerts a force on the bat. That is why you feel a stinging sensation in your hand as the bat vibrates.

Newton's third law states that when one object exerts a force on another, the second object exerts an equal but opposite force on the first object. These forces are sometimes called *action force* and *reaction force* or *force pairs*. These forces act only during the collision itself, which is often a very short period of time.

When the masses of two colliding objects are very different, the effect on the smaller object is greater than the effect on the larger one. When you hit the ball with the bat, the ball flies away but you and the bat do not. When a meteoroid strikes Earth, the force that the meteoroid exerts on Earth is the same strength as the force Earth exerts on the meteoroid. However, the effects are very different. Earth's crust gets a small dent, but the meteoroid is destroyed.

Newton's Second Law of Motion and Collisions

The robots are kicking identical balls; each kick is a collision. The effect of each kick on each ball depends on the ball's initial motion and the force of the kick. The force of the robot's kick causes the ball to accelerate. Remember that a change in the speed or direction of an object is acceleration. The robot is much more massive than the ball, so it accelerates less than the ball during the collision. This example illustrates Newton's second law of motion—the acceleration of an object depends on the mass of the object and the force applied to it *(F = ma)*.

Robots Collide with Identical Balls

An object accelerates in the direction of the net force applied to it. The greater the force applied to the object, the greater the acceleration.

3. If the balls start at rest, the ball kicked with the most force will be moving faster / slower than the other balls after it is kicked. The ball with the greatest velocity will travel the farthest/ least after it is kicked. The yellow/red/blue robot kicked with the most force. The evidence is the distance the ball traveled/size of the robot.

4. Draw A satellite collides with debris in space. Draw a picture showing the collision. Show the forces and indicate their likely effects.

Newton's First Law of Motion and Collisions

Automotive engineers study collisions to protect passengers from harm in collisions such as this one.

Different objects behave differently during collisions. Many objects actually deform, or change shape, during a collision. Cars are designed to deform in specific ways during a collision. This is an important safety feature because it reduces the force acting on the passengers in the car. Some of the energy from the moving car goes into deforming the vehicle rather than affecting the passengers.

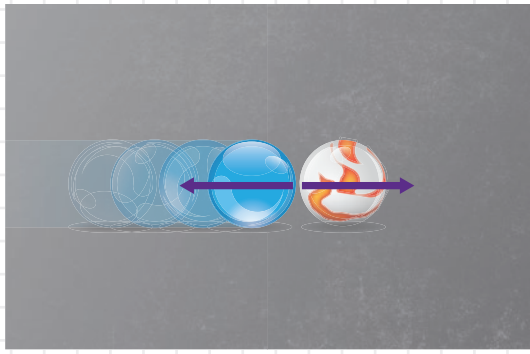
Recall that Newton's first law of motion describes the inertia of an object, or an object's resistance to a change in motion. How does inertia affect collisions? Look at the car crash shown. You know that when the car stops, the passengers will continue to move due to inertia. This is why we have seat belts to stop passengers during a collision. How does inertia explain the crumpling of the car during the collision?

5. **Collaborate** With a partner, analyze the collision shown in the photo. Use your knowledge of Newton's laws of motion and collisions to describe the motion of the car throughout the collision.

Simple Collisions

In a simple collision, deformations and energy losses are not considered. A simple collision can be analyzed using Newton's laws of motion. Analyzing simple collisions can help engineers and scientists explain more complex collisions, such as a car crash. Let's look at some examples of simple collisions to see how the masses of the objects in a collision affect the objects' motions before, during, and after a collision. As you think about the following examples, consider how each of Newton's laws of motion can be applied to each situation.

Collisions between Objects with Equal Masses

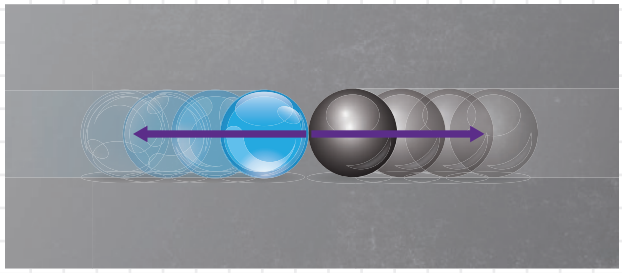


During the collision, each marble exerts a force on the other marble. This force pair is shown in the image.

Consider the two marbles shown in the image. Both marbles have the same mass. Before the collision, the blue marble is moving from left to right. The orange marble is at rest. From Newton's first law, we know that the blue marble will continue to move, and the orange marble will stay at rest—until they collide, that is. When the marbles collide, Newton's third law tells us that the force each exerts on the other is equal in strength and opposite in direction. Because the masses are the same, Newton's second law tells us that the acceleration of the balls during the collision will also be equal and opposite. The blue marble accelerates in the direction of the force exerted on the blue marble. In this example, this acceleration is in the opposite direction of the marble's original velocity. So the blue marble's speed will decrease. One possible result of this collision would be that the blue marble stops moving and the orange marble begins moving to the right at the same speed the blue marble initially had.

6. Explain how the collision would or would not change if both marbles were moving before the collision, instead of only the blue marble moving. Use Newton's laws of motion to support your reasoning.

Collisions between Objects with Different Masses



A glass marble collides with a steel ball. Both have the same dimensions, but the steel ball has a greater mass.

Many collisions involve objects with different masses. We know that each ball in the collision shown will experience an equal and opposite force. From Newton's second law, we know that the acceleration of an object depends on its mass and the applied force. How will that relationship affect a collision between two objects with different masses?

7. Which of the statements are true about the collision of two objects with different masses based on Newton's laws of motion?

A. Each object experiences an equal and opposite force.

B. The more massive object will exert a greater force on the less massive object.

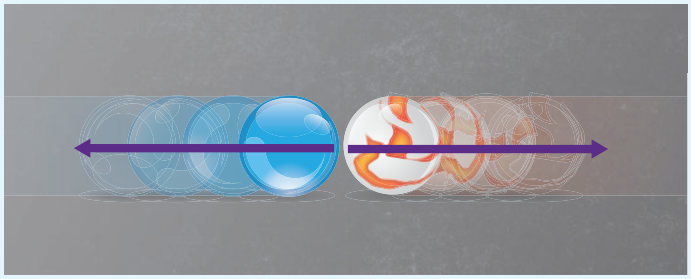
C. Each object will accelerate in an opposite direction from the other but at a different rate.

D. The less massive object will accelerate due to the force of the collision, but the more massive object will not.

Do the Math

Analyze Acceleration During a Collision

Before the collision, the two marbles shown are moving at equal speeds in opposite directions. Both marbles have the same mass. When two objects with the same mass collide, Newton's laws tell us that they will accelerate the same amount but in opposite directions. Recall that force, velocity, and acceleration have both magnitude and direction. We use positive and negative signs to indicate the direction of each of these quantities.



Notice that the force arrows on each marble are equal in magnitude and opposite in direction.

8. Before the collision, the blue marble is moving from left to right, and it has a velocity of 2 m/s. The orange marble is moving at an equal speed but in the opposite direction. What is the velocity of the orange marble before the collision?

9. During the collision, both marbles accelerate to a stop, or 0 m/s. Use the formula $V_{final} - V_{initial}$ to calculate the change in velocities for the orange and blue marbles.

Orange marble: 0 m/s – (–2 m/s) = 2 m/s

Blue marble: 0 m/s – 2 m/s = _____

10. What can you say about the change in velocities of the marbles?

11. The velocities of the marbles change, so we know that the marbles accelerate. Acceleration is the rate of change of velocity, which is the change in velocity divided by time. To calculate acceleration during a collision, the time is the duration of the collision, which is the same for both objects in the collision. What can you say about the accelerations of the blue and orange marbles during this collision?

12. Use Newton's laws of motion to write a description of the motion of both marbles during this collision.

Collisions with Objects in Contact

What happens when an object collides with a second identical object that is touching a third identical object? The object in the middle effectively transfers the force of the collision to the third object. The third object will then move as a result of the collision, but the second object will not move. When the balls are moving, they have *kinetic energy*. This energy is transferred to the other balls during each collision. During each transfer, there are some losses as the energy is transformed into other types of energy such as sound energy and thermal energy. You can hear a clicking sound during each collision as evidence of these losses.

The Newton's cradle is an example of how collisions work when objects are in contact.

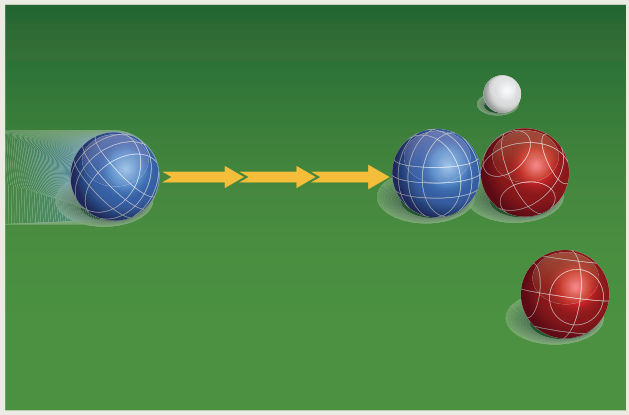
13. Language SmArts Based on Newton's laws of motion, you might expect that once the Newton's cradle is set in motion, it will stay in motion forever. Make an argument about whether this is true or not. Support your claim with evidence.

EVIDENCE NOTEBOOK

14. Why might a smartphone be damaged when it falls on a hard surface? Record your evidence.

Analyze a Bocce Shot

In the game of bocce, two teams roll their balls toward a target ball. The goal of the game is to have the ball that is the closest to the target ball after each team throws their balls.



15. The blue team is rolling one of their balls toward another of their balls, which is touching an opponent's ball as shown. What do you predict will happen when the balls collide? Will this be a good shot for the blue team?

Engineering a Solution to a Collision Problem

Effects of Collisions

You know from experience that collisions have different effects depending on the objects involved and the motion of the objects just before the collision. A soccer ball has a greater acceleration when it is kicked with a greater force than when it is kicked with a lower force. If a ball is moving toward a player, a kick will have a different effect than if the ball is not moving. A tennis ball bounces differently on a clay surface compared to a grass surface or a hard surface.

16. The bird flies over different surfaces. How will the surface onto which the bird drops the clam affect whether the clam will open?

A bird drops a clam to break the shell open for food.

The bird uses a collision to its advantage. Humans also use collisions to achieve a goal, such as hammering a nail. Unfortunately, not all effects of collisions are desirable; they can be dangerous or damaging. Imagine the hammer hitting your thumb instead of the nail. Ouch! Because damaging collisions will happen sometimes, engineers work to develop solutions to reduce the damage caused by collisions.

17. Draw Imagine a stunt person falling onto an airbag. The airbag is designed to slowly bring the stunt person to a rest. Imagine this collision in slow motion. Draw a series of three images showing the motion of the stunt person at the beginning, middle, and end of the collision with the airbag.

18. Discuss With a partner, discuss how the motion of the stunt person relates to the forces acting on the stunt person during the collision.

Hands-On Lab

Test Packing Materials

Packaging designers need data on packing materials in order to choose the best materials to meet their needs. Test engineers design tests to collect this data. In this lab, you will design a testing method and perform tests on different packing materials. A successful testing method is repeatable and will give engineers the data they need to choose the best materials for their packing needs.

MATERIALS

- box, cardboard, about 6 in. on each side
- bubble packing
- cotton balls
- egg, hard-boiled
- meterstick
- rubber bands
- scale
- tape or glue

Procedure and Analysis

STEP 1 The list below is an incomplete list of criteria and constraints for this engineering design problem. With your group, discuss the engineering problem and add at least one constraint and one criterion to better define the problem.

Criteria	Constraints
Testing method can be used to test a variety of materials.	Testing method can be performed with materials available in the classroom
	Testing can be completed within one class period.

STEP 2 Brainstorm ideas for testing methods that can be used to evaluate the effectiveness of different packing materials. Do not evaluate the ideas yet. Record each idea in a notebook.

STEP 3 Choose a method from Step 2 that you will implement. Draw or describe the method, and explain why it is the most promising solution. Show your method and explanation to your teacher.

STEP 4 Implement your chosen testing method, and record the test results for each of the packing materials being tested.

Students examine their egg after a test.

STEP 5 Does your testing method satisfy your criteria and constraints? Describe how you might improve your testing method.

STEP 6 Based on your testing, what qualities make a material useful for protecting an item during a collision?

Energy and Collisions

Objects and systems may contain different amounts and types of energy. When an object is moving, it has kinetic energy. What happens to this energy during a collision? Some of the energy remains with the object. Some of the energy is transferred from one object to the other during the collision. Some of the energy is transformed into other forms such as sound energy or thermal energy. If an object in a collision is made of an elastic material, the energy may temporarily be stored as *elastic potential energy* as the object deforms. When the object returns to its original shape, this elastic potential energy transforms back into kinetic energy. Whenever energy is transformed into another form, some of the energy is lost. These losses may be desirable depending on the situation. For example, when a percussionist hits a drum, some of the energy is transformed into sound energy and is lost from the system. While Newton's laws of motion can be used to describe the motion of objects during a collision, sometimes other concepts are needed to fully analyze a collision.

19. Language SmArts The image shows a tennis ball during a collision with the ground. Explain in detail why the tennis ball bounces. Use Newton's laws of motion and information from the text to support your reasoning.

A tennis ball deforms as it bounces on the ground.

EVIDENCE NOTEBOOK

20. How can the lab results help you design protection for a smartphone screen during a collision? Record your evidence.

Do the Math | Analyze the Effect of Collision Duration on Acceleration

When objects collide, the duration of the collision is measured from the time of initial contact to the time when the objects are no longer in contact or when they have stopped accelerating relative to each other. If an object deforms during a collision, the duration of the collision is extended. Do the math to see how changing the duration of a collision affects the magnitude of the acceleration.

21. Objects A and B, each with a mass of 20 kg, collide with a much larger object. Both A and B have a velocity of 10 m/s just before the collision and come to a full stop after the collision. The duration of the collision of object A is 0.001 s. The duration of the collision of object B is 0.002 s. Calculate the acceleration of each object using the formula $a = (V_{final} - V_{initial})/t$.

Object A $\quad \dfrac{0\text{ m/s} - 10\text{ m/s}}{0.001\text{ s}} = \dfrac{-10\text{ m/s}}{0.001\text{ s}} = -10{,}000\text{ m/s}^2$

Object B $\quad \dfrac{0\text{ m/s} - 10\text{ m/s}}{\square\text{ s}} = \dfrac{-10\text{ m/s}}{\square\text{ s}} = \square\text{ m/s}^2$

22. Use the accelerations of objects A and B to explain how a collision's duration affects the object's acceleration.

Design Packaging

Packages are shipped all over the world. Often what is being shipped needs to be protected from collisions that occur during shipping. Consumers and companies desire minimal packaging to minimize waste and package weight, but the product must be protected.

23. Explain how you would begin designing a solution to the problem of protecting a fragile item, such as a laptop, during shipping.

A drone delivers a package.

Continue Your Exploration

Name: **Date:**

Check out the path below or go online to choose one of the other paths shown.

Careers in Engineering

- **Wrecking Ball Demolitions**
- **Propose Your Own Path**

Go online to choose one of these other paths.

Crash Test Engineer

You have probably seen videos of crash test dummies in a car collision. Crash test engineers design ways to test the effects of a car collision on a car's passengers and to improve car designs to be safer. Recording devices on crash test dummies measure forces experienced by the bodies during a collision. Engineers then analyze this data and use it to design better safety devices for vehicles. Safety measures include devices such as safety belts and airbags, which apply forces directly to passengers to protect them. Car bodies themselves are engineered to deform in specific places to protect the passengers. A crash test engineer often has a degree in mechanical engineering or industrial engineering. The job requires an understanding of physics, math, and how to use computers to analyze data.

A crash test is performed with a cyclist colliding with the side of a car. Video and sensors on the crash test dummies record data about the acceleration and forces experienced by the crash test dummies.

Continue Your Exploration

1. Based on the description of a crash test engineer's job, which of these engineering tasks would the engineer work on? Choose all that apply.
   - **A.** testing prototypes of a new design to determine whether they meet safety criteria
   - **B.** choosing materials used in automobile manufacturing
   - **C.** studying customer preferences to improve marketing
   - **D.** using a computer to analyze large amounts of data

2. Which of the following may affect a passenger's safety during a collision?
   - **A.** the mass of the automobile in which the passenger rides
   - **B.** the mass of the automobile that collides with the passenger's vehicle
   - **C.** the velocity of the passenger's vehicle
   - **D.** the acceleration of the passenger's vehicle during the collision

3. Automobiles did not always have safety devices such as safety belts, airbags, and roll cages. What societal needs led to the creation of these safety measures and the career of crash test engineering?

4. **Collaborate** Work with a partner or a group. Consider the engineering design process involved in making cars and trucks. Make a list of other jobs in the automotive industry that could also be filled by mechanical or industrial engineers.

Can You Explain It?

Name: **Date:**

How can Newton's laws be applied to protect a smartphone screen during a collision?

EVIDENCE NOTEBOOK

Refer to the notes in your Evidence Notebook to help you construct an explanation for how to protect a smartphone screen during a collision.

1. State your claim. Make sure your claim fully explains how a smartphone can be protected during a collision.

2. Summarize the evidence you have gathered to support your claim.

Checkpoints

Answer the following questions to check your understanding of the lesson.

Use the photo to answer Questions 3 and 4.

3. The mat in the photo helps protect the gymnast by decreasing / increasing the duration of the collision between the gymnast and the floor. Decreasing / Increasing the duration of the collision decreases the acceleration / velocity of the gymnast during the collision.

4. Which of the following criteria are satisfied by the mat in the photo?

A. does not interfere with gymnast during a routine on the rings

B. is easily transported by a single person

C. protects a gymnast from injury during a dismount from the rings

D. fits in a small car

Use the photo to answer Question 5.

5. The photo shows evidence of meteors colliding with the moon. According to Newton's laws, what can be said about these collisions?

A. During each collision, the moon exerted a greater force on each meteor than each meteor exerted on the moon.

B. The moon and meteors exerted equal but opposite forces on the each other.

C. The collisions were so small that no forces acted on either the moon or the meteors during the collisions.

D. Because the moon has no atmosphere, Newton's laws cannot be applied to the collisions between the moon and meteors.

6. In a simple collision between two objects, Newton's laws of motion can be used to describe the motion of which of the objects?

A. Both objects

B. Only objects that are moving before the collision

C. Neither object

Interactive Review

Complete this section to review the main concepts of the lesson.

Newton's laws of motion can be used to describe the motions of objects involved in a collision.

A. How can Newton's laws of motion be used to analyze the collision between two objects?

The engineering design process can be used to develop a solution to an engineering problem, including a problem of objects colliding.

B. Collisions may cause unwanted damage to an object. Describe how the engineering design process can be used to design a solution to protect an object during a collision.