HOW WILL IT MOVE?

Force and Motion

IQWST LEADERSHIP AND DEVELOPMENT TEAM

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About the Publisher

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Contents

SCIENTIFIC PRINCIPLES

A scientific principle states a scientific idea that is believed to be true based on evidence. As your class decides on new principles in this unit, add them to the list.

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DRIVING QUESTION NOTES

Use this space to organize and record ideas that will help you answer the Driving Question or your own original questions.

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Activity 1.1: Anchoring Activity

What Will We Do?

We will observe a device called a Magnetic Cannon and investigate its behavior under different conditions.

Procedure

Your teacher will give your group a Magnetic Cannon. Experiment with it to see how it works and discover things that interest you. While you are experimenting with the cannon, think about what you are seeing.

Record your observations and questions in the Data Collection/Observation section. You might try

- watching what happens as the cannon fires.
- changing the number of balls on the shooting side.
- holding the single ball and letting the cannon move, in reverse, toward it.

Data Collection/Observation

Activity 1.2: Driving Question Board

What Will We Do?

We will think about the Magnetic Cannon and other things that move, and ask questions about how they work.

Procedure

- ☐ a. List some questions that you have about the cannon and how it works. Do you also have other questions about forces and motion? Do you wonder about how other things work? Is there another question you could ask that might help you figure out how the cannon works? Your class will use your questions to organize the rest of the unit, so be sure to ask about anything you think it would be interesting to learn more about.
- ☐ b. Discuss your questions with your group. You might ask some of the same questions as other people do. If that happens, write just one sticky note to represent that question. There is no limit to the number of questions your group can have.
- ☐ c. Look at the categories on the Driving Question Board. Which categories do your questions fit? Discuss this in your group, so when it is time to share your questions with the whole class, your group has already made decisions.

Conclusion

The Driving Question Board that you, your classmates, and your teacher have created will help you keep track of your progress during the unit. After every activity, you should ask, "How does today's activity help me understand how the Magnetic Cannon works?"

Lesson 1 Reading One: Newton's Cradle

Getting Ready

Look at the device in this photo. Like the Magnetic Cannon you investigated in class, when one ball hits the others, a ball at the other end flies out. This device is called Newton's Cradle because it is named after Isaac Newton. Newton was a very important scientist, and learning about him can help you be more knowledgeable about how scientists work to figure things out.

Newton's Apple

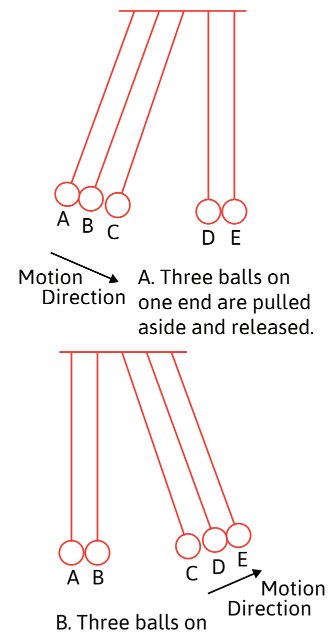
What would you think of if you saw an apple fall from an apple tree? You probably would not think much about it. Isaac Newton, whom many people consider the greatest scientist ever, thought about it a lot. Newton was a physicist and a mathematician. He lived in England more than 300 years ago (1642–1727). According to the story, when Newton once saw an apple fall from a tree in his orchard, he suddenly thought that falling was not such an obvious thing. He wondered: "Why does an apple always fall straight down? Why does it not fall sideways or upward?" These questions led Newton to develop a theory of gravity, which explains that all objects attract each other because of gravity. Gravity makes things fall on Earth. As strange as it may sound, gravity also makes the moon go around Earth and the planets go around the sun.

Newton spent a great deal of time investigating forces and motion. He developed important principles that describe the relationship between motion and forces. You will learn about these principles in this unit.

Thinking about Newton's Cradle

Now that you know Newton developed ideas about gravity, and about force and motion, it probably makes sense that this device was named after him. Newton's Cradle is often used to demonstrate some basic principles of energy, forces, and motion.

Newton's Cradle usually consists of an odd number of identical steel balls (usually five or seven), each hanging from a sturdy frame by two strings. The balls are carefully aligned so that they barely touch each other. What happens when a ball at one end is pulled aside and then released? What happens when two are pulled to one side and released?



A. Three balls on one end are pulled aside and released.

B. Three balls on the other side swing up.

When you pull aside a ball at one end of the cradle and then release it, it swings downward until it hits the ball next to it. What happens then is surprising. The ball on the far end of the cradle swings away from the others. All the other balls remain at rest. If you pull two aside on the same side and drop them together so that they strike the others, two balls swing out from the other end. All the other balls, including the two you dropped, remain at rest. What would you expect to happen if you drop three or four balls? Regardless of the number of balls you drop, it will always be the same number of balls that swing out on the other side. The others stay at rest. The moving balls stop and hang straight the instant that they hit the others.

If you have access to the Internet, you can search for a "virtual Newton's Cradle" to continue to experiment with it on your own.

Why do you think that if you drop two balls, exactly two balls rise on the other side at a similar speed? Why doesn't one ball fly off quickly instead? Why don't three balls fly off slowly? This is a difficult question, but try your best to think about what you know and what might make sense.

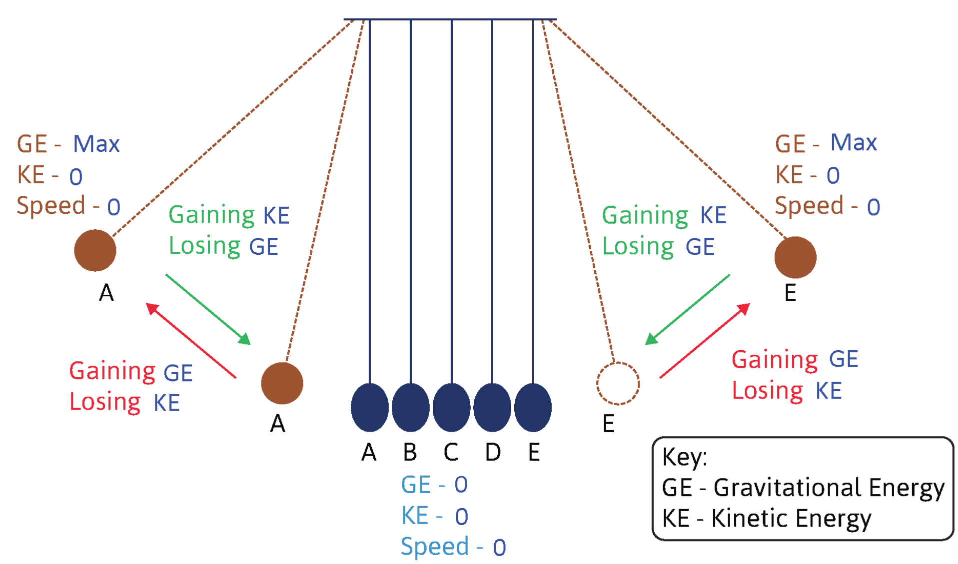
Energy Transformations in Newton's Cradle

One of the ways to understand how Newton's Cradle works is to consider which energy transformations occur as it works. In the past, you may have learned some important concepts about energy:

- There are different types of energy (gravitational, kinetic, elastic, and chemical).
- One type of energy can change into another type. Scientists call this energy transformation.
- The total amount of energy in a system does not change.

Before you continue reading, stop for a minute and think: What types of energy transformations occur when Newton's Cradle is operating? What types of energy are transferred to the cradle's surroundings?

As in pendulums, roller coasters, bouncing balls, and falling apples, transformations between gravitational energy and kinetic energy are what make Newton's Cradle work. Read each of the following steps, and then look at the drawing to help you think about what is happening.



- When you pull Ball A aside, it gets higher and gains gravitational energy. (This energy is transferred to it from your hand.)
- When you release Ball A, it loses gravitational energy as it falls, but it gains kinetic energy. Its gravitational energy is transformed into kinetic energy.
- When Ball A hits Ball B, the kinetic energy of Ball A is transformed into elastic energy because the ball gets compressed. The amount of compression is very small because the ball is made of steel, but it is still there.
- The elastic energy is transferred from Ball A to Ball B, which gets compressed.
- The elastic energy is transferred from Ball B to Ball C and so on, all the way up to Ball E.
- Ball E's elastic energy is transformed into kinetic energy, and in response it starts moving sideways and upward.

At this point, the energy Ball A had at the start has been transferred to Ball E. A very small amount has been transferred to the surrounding air as sound energy, and another small amount has been transformed into thermal energy, but just focusing on the gravitational-elastic-kinetic energy transfer and transformation is helpful for now. That is why Ball E moves away from the other balls at the same speed that Ball A hit Ball B. While moving upward, Ball E's kinetic energy is transformed back into gravitational energy. Once all its kinetic energy has transformed into gravitational energy, Ball E stops rising. It is now at its highest point, which is the same height at which Ball A was released. This process repeats itself in reverse when Ball E swings back toward the other balls.

Thus Newton's Cradle involves four types of energy transformations:

1. Gravitational energy to kinetic energy
2. Kinetic energy to gravitational energy
3. Kinetic energy to elastic energy
4. Elastic energy to kinetic energy

In addition, the cradle involves the transfer of elastic energy between different balls. Although the amount of energy each ball has changes during these energy transfers, the total amount of energy possessed by the cradle as a whole (if you ignore the little bits of energy transferred to the surrounding air) does not change—it is just transferred from one component of the system to another component.

If you visited a virtual Newton's Cradle website or played with the real device, you might have noticed that after a few swings, the balls slow down. The height they reach gets shorter and shorter until they finally stop moving. If energy is transformed from one type to the other and transferred between the different balls in the device, why does the motion in Newton's Cradle finally stop? (Hint: Think about something you decided to ignore earlier in the reading.)

Summary

By now you understand some things about how Newton's Cradle works. You can explain why the speed and the height of the balls are equal in both sides of the device, but you may not be able to explain why the balls in the center do not move or why the same number of balls move in both sides. In order to understand this phenomenon, you need to learn more about forces and motion. As you continue investigating motion during this unit, you will learn how and why things move the way they do.

Activity 2.1: Analyzing Apparatuses

What Will We Do?

We will observe four devices to figure out what forces are (1) acting between the components and (2) influencing how the apparatus moves.

SAFETY GUIDELINES

Balloons are used in the activity. Inform your teacher and use appropriate precautions if you have a latex allergy.

Procedure

Your teacher has set up stations, each featuring a different apparatus. At each station is also a card with the name of the device and instructions about how to make it work. Read the instructions and carry out the activity. Record what happens and what each apparatus is made of. You will have just a few minutes at each station, so make careful observations as efficiently as possible.

When you return to your seat, your teacher will give you time to answer questions about each device (see the following). Make sure you gather all the information from each station that you will need to answer these questions.

Data Collection/Observation

Station #1 – Flying Balloon

- Which components of the apparatus affect its motion? Construct a model of the apparatus that shows these components.

- What are the forces acting on the components of the apparatus that influence its motion? Add these forces to your model.

- How does the apparatus work? Write an explanation using your model.

Station #2 – Floating Magnets

- Which components of the apparatus affect its motion? Construct a model of the apparatus that shows these components.

- What are the forces acting on the components of the apparatus that influence its motion? Add these forces to your model.

- How does the apparatus work? Write an explanation using your model.

Station #3 – Air-Powered Car

- Which components of the apparatus affect its motion? Construct a model of the apparatus that shows these components.

- What are the forces acting on the components of the apparatus that influence its motion? Add these forces to your model.

- How does the apparatus work? Write an explanation using your model.

Station #4 – Magnetic Cannon

- Which components of the apparatus affect its motion? Construct a model of the apparatus that shows these components.

- What are the forces acting on the components of the apparatus that influence its motion? Add these forces to your model.

- How does the apparatus work? Write an explanation using your model.

Activity 2.2: Systems and Contact Forces

What Will We Do?

We will analyze some scenarios to figure out what forces are acting between the components.

Procedure

- ☐ a. Draw a simple model of the two vehicles and the rope connecting them.

- ☐ b. Which components of this system interact with each other?

☐ c. When people push each other, is there one force acting or two?

☐ d. How many forces does each person apply?

☐ e. How many forces act on each person?

☐ f. When you sit in your chair, do you push down on it?

☐ g. Does your chair push up on you?

☐ h. Can you think of an example where contact forces are not paired?

☐ i. Return to the model you drew of the two vehicles and rope. Add pairs of forces to the model.

Making Sense

1. What can you conclude about pairs of forces, pushes and pulls, and the directions of the forces?

Homework 2.2: The World's Greatest Sandwich

Ofra's Deli has the reputation of making the best sandwiches in the world. The photo shows Ofra's masterpiece, called the "Imperial." It is made of six layers—freshly-baked sourdough country bread, honey-smoked turkey breast, ruby-ripe vine tomatoes, Gouda cheese, Romaine lettuce, and another slice of bread. Ofra says the secret to her masterpiece is knowing exactly how much force each layer should apply to the others.

Construct a model describing the "Imperial" as a system, its components, and the contact force pairs acting between the components. Also, make a table that lists the contact forces between the components.

Activity 2.3: Forces that Act at a Distance

What Will We Do?

We will investigate three forces that are not contact forces—gravitational forces, magnetic forces, and electrical forces.

You learned that all contact forces come in pairs. Before you begin, think about this: Do forces that act at a distance come in pairs as well? Give an example as evidence to support your ideas.

Procedure

Your teacher will give you and your partner a pair of magnets. Experiment with them for a while and try to figure out the answers to the following questions.

- ☐ a. Do the magnets apply a force to each other, or does only one apply a force to the other? What is the evidence to support your answer?

  They apply a force to each other. If I hold one magnet, the other magnet is pulled or pushed away. If I hold the second magnet, the first magnet is pulled or pushed away.
- ☐ b. Do the magnets have to be in contact to apply a force to each other or can they act at a distance?

  They act at a distance. They attract and repel each other even when they are not touching each other.
- ☐ c. Do the magnets apply pull forces or push forces to each other, or can they apply both? What is your evidence?

  When holding one magnet, we see that it can pull the other magnet toward it or push it away. Therefore, they can apply both pull and push forces.
- ☐ d. Do these forces become stronger or weaker as the magnets get nearer to each other?

  The forces get stronger as the magnets get nearer to each other.

Making Sense

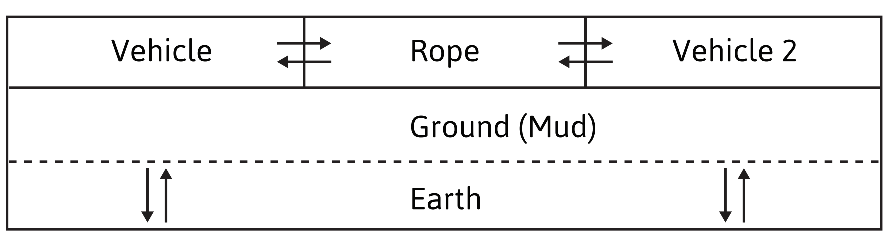
1. What type of force keeps atoms together in a molecule?

2. What type of force makes things fall, makes the moon orbit Earth, and makes Earth orbit the sun?

3. Are these forces contact forces or do they act at a distance? How do you know?

4. Do forces that act at a distance come in pairs? Explain your answer and provide some evidence to support it.

5. Add to the model of the vehicles all the forces that act at a distance. Use dashed lines to represent these forces.



Lesson 2 Reading One: Balance and Force

Getting Ready

Look at the picture. The fork and spoon are hanging off the edge of a toothpick, which, in turn, is hanging off the edge of a glass. This is not a trick photo. No glue was used in setting up the fork and spoon. What is going on? As you read, pay attention to how forces can help you explain how the fork and spoon can be balanced in this way.

Try This at Home!

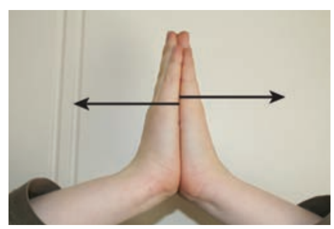
One way to test what you see in the picture is for you to try and do this stunt yourself. For the fork and spoon stunt, you will need a fork, a spoon, a toothpick, and a glass. First, hook the fork and the spoon together the way it is in the picture. Then balance them on a toothpick on the edge of a glass.

When you succeed, you might want to take a picture of yourself with these physics stunts and show them to your friends. If you print the photo, you can attach it here:

Why do the spoon and fork not fall?

Pairs of Contact Forces

In class, you have discussed systems that include pairs of contact forces acting in opposite directions. You discussed doing a high five and that the forces come in a pair. You also talked about examples like a ladder leaning against the wall or an object sitting on a table. You may have been surprised to learn that all contact forces, whether they are pushes or pulls, come in pairs. You saw that even if the objects do not seem to move or to do anything, in each situation there are always two forces. Every object applies one force and is subjected to the other force. If one force is a pull, then the other one will also be a pull, but in the opposite direction. If one force is a push, the other will be a push in the opposite direction. For example, the ladder is pushing the wall, and the wall is pushing the ladder.



Look around the room or look outside. Give an example of two objects applying push contact forces on each other.

Make a drawing of these objects using arrows to show the direction of these forces. Remember that since forces always come in pairs, for every arrow you draw, there should be another one pointing in the opposite direction.

Now, give an example of two objects applying pull contact forces on each other. Make a drawing showing these forces using arrows to show the direction of these forces.

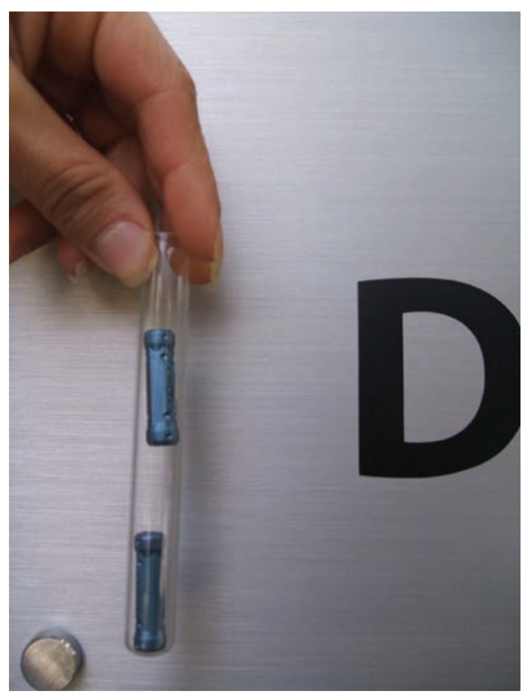
Where are the push forces in the spoon and fork activity? Make a drawing showing these forces. Draw and label the arrows.

There are push forces between the fork and the spoon, between them and the toothpick, between the toothpick and the glass, and between the glass and the table.

Pairs of at-a-Distance Forces

In the last reading, you saw this drawing when you learned about Isaac Newton and gravity. Look at Apple 1. There are contact forces acting between this apple and the branch it is hanging on. The apple is pulling the branch down and the branch is pulling the apple up.

The apple is also being pulled by Earth's gravity. Earth's gravity pulls the apple from a distance, and at the same time, although we usually do not notice this, the apple pulls Earth from a distance. Although it seems strange to think that the apple pulls Earth, it really happens! We never notice this because Earth is so heavy; so being pulled by an apple does not really affect it at all.



Which of the marked apples in the picture interact with Earth by at a distance forces? Explain your choice.

a. Apple 1
b. Apple 2
c. Apple 3
d. All of the above

Another kind of force you have learned about that also acts at a distance is the magnetic force. In class you investigated the Floating Magnets.

In this apparatus, was magnetic force a pull force or a push force?

The next photo shows another contraption that, like the fork and spoon, is weirdly balanced. In it a hammer is underneath a ruler that is hanging off the edge of a table without falling.

If you want to try and build this contraption by yourself at home, you will need a ruler that is not too flexible, a rope, a hammer, and a table. Arrange everything the way it is in the picture. Move the hammer back and forth along the ruler until you reach a position where the whole thing can balance. Do not give up, even if it does not work right away. Keep on trying! Eventually you will find the position in which everything is balanced.

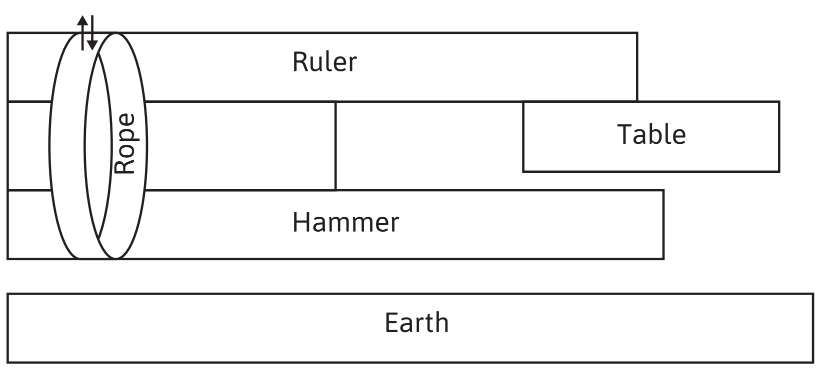
Using what you learned about the fork and spoon stunt, which objects apply forces that act at a distance in the hammer and ruler stunt? Which objects are subjected to at a distance forces?

Modeling the Interactions in the Hammer and Ruler System

According to your answers so far, you can now complete the following interactions table describing the hammer and ruler system, the same way you did in class for the systems you investigated there. Use a "+" sign to represent interaction and a "–" sign to represent no interaction. For example, if you think there are forces acting between the rope and the hammer, draw a "+" sign in the appropriate cells, as shown in the following example.

	Hammer	Rope	Ruler	Table	Earth
Hammer					
Rope					
Ruler					
Table					
Earth					

Use the interactions table to complete the following model describing the system. The system includes all the components that determine whether the hammer falls or not. Use solid arrows to represent contact forces and dashed arrows for at a distance forces. For example, if you think there are contact forces acting between the rope and the hammer, draw solid arrows, as shown in the following example. Remember that all forces always come in pairs!



The hammer interacts through forces with several objects around it. As you will learn in the next few lessons, it is these forces that keep the hammer from falling.

Activity 2.4: Putting Things Together

What Will We Do?

We will revisit the four devices we looked at in the first lesson. We will answer the same questions, only now we will have greater understanding of the forces involved in each device.

Procedure

☐ a. Construct a model of each device that represents its components.
☐ b. Use arrows to represent in each model the forces that affect its motion. Include both contact forces and those that act at a distance.

Data Collection/Observation

Station #1 – Flying Balloon

- The components of the system are
  a. a string,
  b. a straw, and
  c. a balloon.

- The forces acting on the system's components are
  a. a pull contact force between the string and the straw which is threaded on the string,
  b. a push contact force between the balloon and the air inside it,
  c. a push contact force between the straw and the air inside it,
  d. a pull contact force between the straw and the balloon, and
  e. pull forces that act at a distance between Earth and all the other components of the system.

Station #2 – Floating Magnets

- The components of the system are
    a. two magnets,
    b. a test tube, and
    c. Earth.

- The forces acting on the system's components are
    a. a push force that acts at a distance between the two magnets,
    b. push contact forces that act between the test tube and the magnets, and
    c. pull forces that act at a distance between Earth and all the other components of the system.

Station #3 – Air-Powered Car

- The components of the system are
    a. the car,
    b. the fan mounted on the car,
    c. the table on which the car moves,
    d. the air surrounding the car and fan, and
    e. Earth.

- The forces acting on the system's components are
    a. a push contact force between the air and the fan,
    b. a push contact force between the fan and the car,
    c. a push contact force between the car and the table, and
    d. pull forces that act at a distance between Earth and all the other components of the system.

Station #4 – Magnetic Cannon

- The components of the system are
  - a. five ball bearings,
  - b. two magnets,
  - c. a table on which the magnets and ball bearings are placed, and
  - d. Earth.

- The forces acting on the system's components are
  - a. contact push forces between each ball bearing and its neighbor balls;
  - b. push contact forces that act between Ball A, Ball B, and the magnets they touch;
  - c. pull forces that act at a distance between the magnets and all the ball bearings;
  - d. a pull force that acts at a distance between both magnets;
  - e. push contact forces between the table and all the balls and magnets; and
  - f. pull forces that act at a distance between Earth and all the other components of the system.

* The rails that the Magnetic Cannon sits within only keeps the balls and the magnets aligned. There is negligible impact on system.

Activity 3.1: Objects that Begin Moving

What Will We Do?

We will use models to figure out whether and how a system will begin moving.

Procedure

☐ a. Your teacher demonstrated two simple instances of objects beginning to move—a tennis ball that was tapped and a marble that was shot out by a stretched rubber band. Explain why the objects began to move. Write a single explanation that is good for both objects.

☐ b. Using what you learned in Lesson 2, make interaction tables showing all the interactions involved in both cases, and then draw models that show the various components of each system, and the forces that act on them and that they apply.

☐ c. What are the three forces that act on each object?

☐ d. Which of these forces act horizontally and which act vertically?

☐ e. Which of these forces can cause each object to begin moving?

Activity 3.2: More Objects that Begin Moving

What Will We Do?

We have determined that the beginning of motion is always caused by forces. In this activity, we will consider other objects that begin to move, to verify whether this statement is always true.

Procedure

☐ a. Your teacher will give you and your partner a tennis ball. With the ball lying on a table, push it from one side and have your partner push it from the other side. Depending on how hard each of you pushes, there are three possible scenarios:
   1. The ball will move away from you and toward your partner.
   2. The ball will move away from your partner and toward you.
   3. The ball will not move.

☐ b. Construct one interactions table and one model that represent all three of these scenarios.

- ☐ c. What are the four forces that act on the ball when it lies on the table and is pushed by you and your partner's hands?
- ☐ d. Which forces do you think influence the ball's horizontal motion? Why do the others not affect its horizontal motion?
- ☐ e. What happens if the force applied to the ball by your hand is greater than the force applied to the ball by your partner's hand? Explain.
- ☐ f. Suppose the ball was pushed with both hands but Hand 1 pushed harder than Hand 2. The ball responds in a certain manner. Can you get the ball to respond in the same manner while pushing it with only one hand? If yes, with which hand should you push the ball and how hard should you push it? How hard should you or your partner push?
- ☐ g. How hard must each of you push to keep the ball motionless?
- ☐ h. Draw a free-body diagram of a ball held in your hand before it is dropped.

Making Sense

1. When do two forces that are applied to an object counteract each other?

2. When do two forces that are applied to an object reinforce each other?

3. When do two forces that are applied to an object cancel each other?

4. An object applies forces to several other things around it. Do these forces influence the object's motion?

Homework 3.2
Heavy-Duty Shopping

Imagine a shopping bag full of fresh produce. Every time you pick up such a bag, you pull upward on the handles with force. To figure out the minimum upward force necessary to pick up the bag, do the following:

Make a table of all the interactions involved when the bag is being pulled up by your hand.

Construct a model of the bag as it is pulled upward.

Draw a free-body diagram of the bag.

Which forces does the upward pull of your hand on the bag have to overcome for the bag to begin moving upward?

Activity 3.3: Complex Systems that Begin Moving

What Will We Do?

We will revisit the four devices again and develop models to help us explain why they begin moving in the direction they do.

Procedure

You will not have time to construct free-body diagrams for all four apparatuses in class. Your teacher will tell you which one or two to work on first. Then you will finish working on the others as homework.

In Lesson 2, you constructed models that represented these apparatuses and their interactions with their surroundings. Use these models to help you construct the free-body diagrams. To help you figure out which parts of the systems described in your models you need to focus on, here are a few hints:

☐ a. In the Floating Magnets, explain why the upper magnet floats.

☐ b. In the Magnetic Cannon, explain why the last ball begins moving.

☐ c. In the Air-Powered Car, think of the car and the fan as a single object to figure out why it starts moving horizontally.

- ☐ d. In the Flying Balloon, treat the balloon and the straw as a single component to explain why it starts moving along the thread.

- ☐ e. What are the two forces that are applied to the upper magnet?

- ☐ f. Which of these forces pull or push upward, and which pull or push downward? Explain.

- ☐ g. What needs to be the relation between the two forces to cause the upper magnet to float without moving?

- ☐ h. When will the magnet start moving up or down? Explain.

- ☐ i. Does the lower magnet float as well? Explain.

- ☐ j. Which horizontal forces act on the last ball?

- ☐ k. How do you know what is the direction of these forces?

- ☐ l. What must be the relationship between these forces for the last ball to begin moving outward?
- ☐ m. Why do you think the car and the fan can be thought of as a single object?
- ☐ n. Which horizontal force acts on the car-fan?
- ☐ o. How can the air apply a force to the car-fan?
- ☐ p. In which direction does the air push the car-fan?
- ☐ q. Why can the balloon and the straw be thought of as a single object?
- ☐ r. Which horizontal force acts on the balloon-straw?
- ☐ s. How can the air apply a force to the balloon-straw?
- ☐ t. In which direction does the air push the balloon-straw? Explain.

Making Sense

1. Under what conditions do forces counteract each other?

2. Under what conditions do forces reinforce each other?

3. Under what conditions do forces cancel each other?

Lesson 3 Reading One: Why Does an Object Start Moving?

Getting Ready

How Does Cupid Shoot Arrows?

Cupid is a famous Valentine symbol. In mythology, he shoots arrows at people, causing them to fall in love. In real life, bows and arrows are usually used as weapons for hunting or for sport. You may have seen toys with foam or plastic arrows. All arrows, even in a toy set, are shot in much the same way. What causes an arrow to start moving?

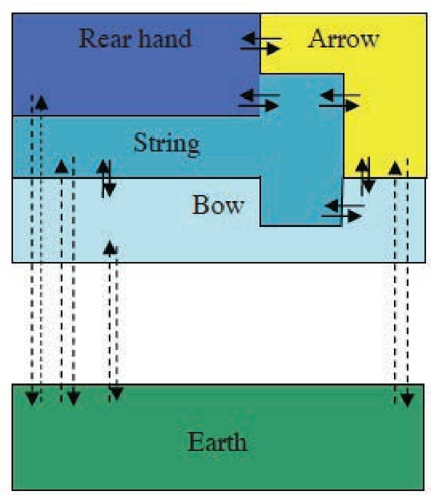
In this reading, you will learn about flying arrows, arm wrestling, and cola that sprays out of its bottle. You will see how forces can explain what happens in each case.

Energy in a Bow and Arrow

You have already learned some things about potential energy. In this photo, when the boy pulls back the arrow and the string, he transfers energy from his body to the bow. The energy in his body was in the form of chemical energy, but it is transformed into elastic energy as the string and the bow bend. When he lets go of the arrow and the string, the elastic energy of the bow is transferred to the arrow, but it is transformed into kinetic energy, which makes it fly. What causes the energy to transfer from the bow to the arrow, transformed from elastic to kinetic? To understand, you need to consider the forces acting on the bow and arrow.

Forces in a Bow and Arrow

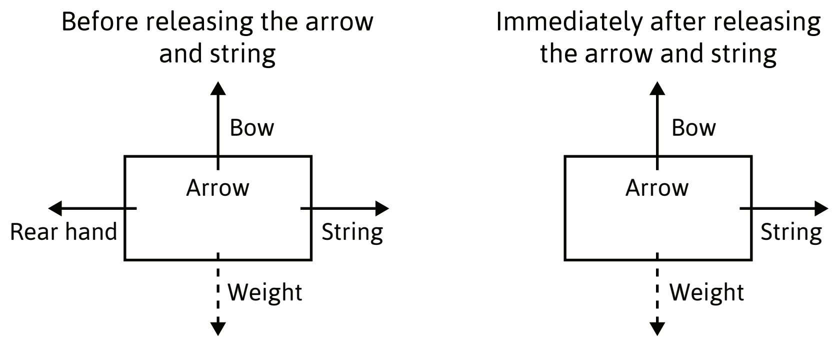
Here is a model of what happens when someone uses a bow and arrow. The model shows the forces involved in the system. The archer's rear hand pulls back on the arrow and the string is pulled forward by the bow. The arrow is pulled back by the hand and pushed forward by the string. It is also pushed upward by the bow, on which it rests. The string is pulled back by the hand and pushed back by the arrow. It is also pulled forward by the bow.



This model shows the components and forces acting in the system before the arrow is released.

The following model shows only the arrow and the forces that act on it, before and after it is released. This model is a free-body diagram of the arrow, before and after it is released. As you learned in class, the model of the whole system shows all the forces that act between all the components of the system. A free-body diagram shows only a single object and the forces that act on it. A free-body diagram helps explain and predict the motion of the object.

Look at the free-body diagrams to answer the following questions.



Free-body diagrams of the arrow

Why do free-body diagrams show only the forces that act on the arrow and not the forces that the arrow applies to other components in the system?

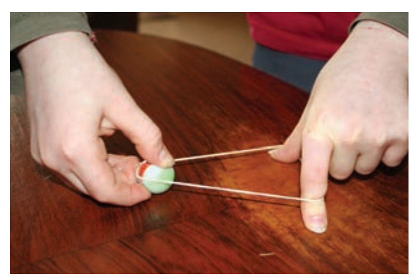
Which forces act on the arrow before it is released? For each force, specify three things: (1) its direction, (2) whether it is a contact force or a force that acts at a distance, and (3) whether it is a pull or a push force.

Why does the arrow not move before it is released? Explain your ideas in terms of the forces that act on the arrow.

In terms of forces, what changes immediately after the arrow is released?

In terms of forces, what makes the arrow start moving?

Starting Motion



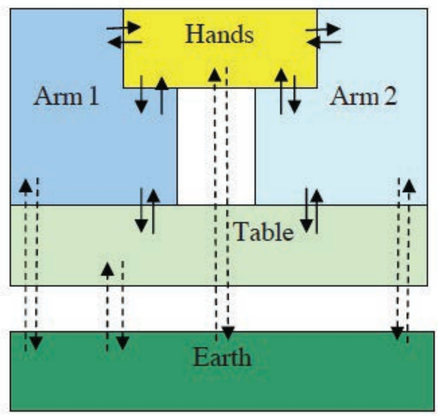
In class you learned that a marble shot by a stretched rubber band began moving because a force was applied to it, just like with the bow and arrow. In both systems, before the marble or arrow is released, there are four forces—two horizontal forces (one pushes forward and the other pulls back) and two vertical forces (one pushes up and the other pulls down).

Physicists say that two forces that are applied to an object in opposite directions counteract each other. That means each one decreases the effect of the other one. If the counteracting forces are the same strength, they cancel each other's effect. Before the marble or arrow are released, the forces acting on them cancel each other; thus they are not subjected to any net force. When the marble or the arrow is released, the backward horizontal force does not act anymore, thus creating a net forward horizontal force.

Who Will Win an Arm Wrestling Battle?

Arm wrestling is another way to think about forces and about starting motion. Imagine two students preparing to arm wrestle. One student is wiry and slim and the other is big and muscular. Who do you think will win? In arm wrestling, the muscles of each opponent's arm apply a force to their own hand, pushing it forward. At the same time, this hand is also subjected to the force of the opponent's hand pushing it backward.

> The hands are often stationary for a long time, but finally they move in one direction. Why?

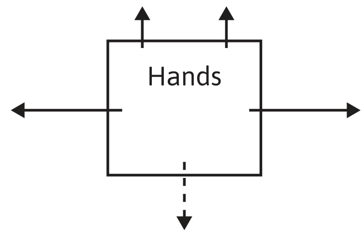


This is a model showing the various objects and forces involved in arm wrestling. Notice that the two opponents' hands are represented together as one object. This is because in arm wrestling, both opponents' hands move together, so it is easier to consider both hands to be one object. The hands could also be represented as separate objects. The results would be the same, but the process would be a bit more complicated to represent.

This is a model showing the various objects and forces involved in arm wrestling. Notice that the two opponents' hands are represented together as one object. This is because in arm wrestling, both opponents' hands move together, so it is easier to consider both hands to be one object. The hands could also be represented as separate objects. The results would be the same, but the process would be a bit more complicated to represent.

Look at the free-body diagram showing the forces that act on the hands at the beginning of the contest.

Complete the diagram. Write near each arrow which object applies the force it is representing.



According to the diagram you completed, if the force of Arm 1 is equal to the force of Arm 2, will the hands move in this contest? Explain your ideas.

After a while, the wiry and slim student gets tired and can no longer push with the same force. Draw a free-body diagram showing the forces that act on the two hands at that point. Remember to represent a greater force with a bigger arrow.

How can these diagrams help predict which of the opponents will win?

In the second diagram, add a bold arrow representing the direction of the hands' motion.

Predicting who will win at arm wrestling is not just about seeing who is bigger and more muscular. Although it might seem surprising, a small girl might be able to beat a large boy, especially if she has long arms and can maintain her strength for a long time. The length of the arm affects how difficult it is to make a strong force. You may learn more about that as you continue in your science studies. There are special ways to twist your opponent's arm, which might be as important, if not more important, than the strength of the arm. The purpose of all these maneuvers is the same—to increase the force applied on the opponent's hand while decreasing the force the opponent can apply in the other direction.

Why Does Soda Spray Out of the Bottle?

Probably everyone has been showered by cola spraying out of an opened bottle. Did you ever wonder why that happens?

What do you think happens? Use your understanding of forces in your explanation.

Many people think that the cola spraying has something to do with the pressure inside the bottle. This is true, but it does not explain the sudden upward motion of the liquid. Forces are the reason motion begins; so to understand this sudden motion, you need to consider the forces acting on the cola.

Before opening the bottle, the cola is pushed by the bottle in almost all directions—from underneath, upward, and from the outside, inside. It is also being pushed downward by the bottle cap. Besides these forces, gravity also acts on the liquid, pulling it downward.

Draw a free-body diagram showing the forces that act on the cola before the cap is removed. Base your drawing on the description in the former paragraph.

Before the cap is removed, all the forces that act on the cola cancel each other. This is called a state of *equilibrium*. The force acting to the right counteracts the one acting to the left. The cap pushes downward and gravity pulls downward, so these forces reinforce each other. Together they counteract the force the bottle applies upward to the liquid inside.

Return to the free-body diagram you made of the bottle of cola. Which of the vertical arrows needs to be the longest? Why?

When you remove the cap, you change the balance of forces; one of the original forces no longer exists. Which force does not act on the cola anymore when you remove the cap from the bottle?

Draw a free-body diagram showing the forces that act on the cola when the cap is removed. Add a bold arrow to represent the direction in which motion begins.

Use the free-body diagram you drew to explain why cola sprays upward out of the bottle when the cap is removed.

The beginning of motion is always caused by forces. In the next few lessons, you will learn about the role of forces in things continuing to move once they have started to move.

Activity 4.1: Measuring Forces (Optional)

What Will We Do?

We will determine how forces are measured and how strong a force is in a spring.

Procedure

Consider the following four questions:

- Does a spring get stretched by the same amount each time the same mass is hung from it?
- Does a spring return to its original shape each time after the mass hanging from it is removed?
- What is the relation between the amount a spring gets stretched and the size of the mass hanging from it?
- How can you tell the size of a mass by the amount it makes a spring get stretched?

Your teacher will give you a spring, a ring stand, a ruler, and three masses. It is your job to design an experiment that will allow you to answer these four questions. After designing your experiment, gather the data, record it in an orderly fashion, and reach a conclusion from the data. Then write a brief report as homework.

Here are some things you should think about that may help you as you design the experiment and carry it out. You will hang from the spring a "mass" made up of metal objects called "washers". First use one, then two, then four washers.

- Rather than directly measuring the amount the spring gets stretched, it may be easier to measure the difference between the lengths of the spring when it is stretched and not stretched.
- Make sure you control unwanted influences that may affect your results.
- If the spring does not get stretched exactly the same each time for the same mass, figure out what is the best result to use.

Make a drawing of your experimental setup. The drawing should include the ring stand, the spring, and a mass hung from the spring.

Draw a model showing the setup and the forces acting between the parts.

Record your results here.

	Mass #1	Mass #2	Mass #3
Measurement #1 [cm]			
Measurement #2 [cm]			
Measurement #3 [cm]			
Average [cm]			

What conclusions regarding the four questions posed at the start of the activity can you reach from your data? Be sure to provide complete explanations for each conclusion.

Activity 4.2: Measuring Force with Probes

What Will We Do?

We will investigate the relationship between mass and weight.

Procedure

Your teacher indicated that to calculate the weight of a known mass in newtons, the value of the mass (in grams) should be divided by 100. Thus the weight of 500g is 500/100 = 5 N.

☐ a. Verify this using a digital force probe. Hang some objects of known mass from a force probe and read the weight of the object. Complete the following table.

Mass [g]	Weight [N]	Mass [g]/100

☐ b. What is the difference between mass and weight?

☐ c. If you know an object's mass, how do you calculate its weight on Earth? Explain your answer for a mass of 400g.

☐ d. If you know an object's weight on Earth, how do you calculate its mass? Explain your answer for a weight of 14 N.

☐ e. Working in groups, connect two force probes together. While one group member pulls the force probes apart or pushes them together, two other group members should take readings from the screens of the data loggers. The student that is pulling the probes apart should hold them on the table so they will not move while the readings are being made. Make sure the probes are parallel; otherwise the results will not make sense. This is because the probes only measure forces along their axes. Your group should make four readings.

Force Probe #1 (N)	Force Probe #2 (N)

☐ f. What can you say about the relationship between these two contact forces with regards to their directions and magnitudes?

Making Sense

1. What general relationship do you think there is between pairs of forces?

Activity 4.3: Revisiting Familiar Apparatuses

What Will We Do?

We will use force probes to measure the strength of each force that appears in the free-body diagrams you made in Lesson 3 for three of the devices we have been investigating.

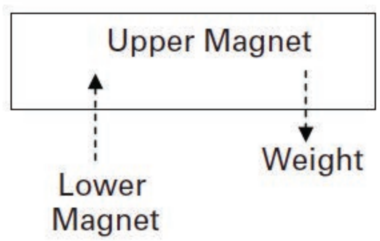
Procedure

You do not need to measure every force in each free-body diagram. Some of the forces cannot be measured. Using what you have learned about forces reinforcing or counteracting each other and the relation of forces to the start of motion, you should be able to figure out the magnitude of each force in each free-body diagram, even those you cannot measure.

Floating Magnets

Weight of Upper Magnet = ______________________________

Force of Lower Magnet on Upper Magnet = ______________________________

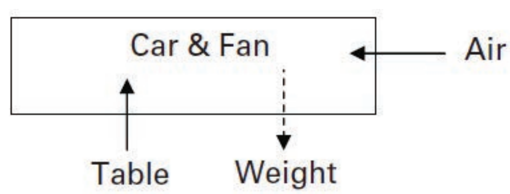


Air-Powered Car

Weight of Car and Fan = ______________________________

Force of Table on Car and Fan = ______________________________

Force of Air on Car and Fan = ______________________________

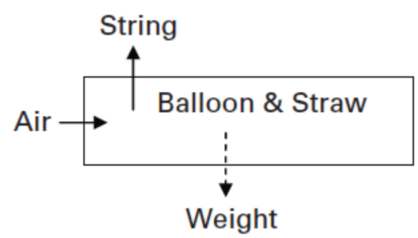


Flying Balloon

Weight of Balloon and Straw = ______________________________

Force of String on Balloon and Straw = ______________________________

Force of Air on Balloon and Straw = ______________________________



Lesson 4 Reading One: What Keeps Things from Moving?

Getting Ready

Two teams play tug-of-war by pulling on a rope stretched between them until one team pulls the other past a mark in the center. One team has especially strong arms. The other team has especially strong legs.

If the strong-arm team won, why would they win? Which forces are involved in a tug-of-war?

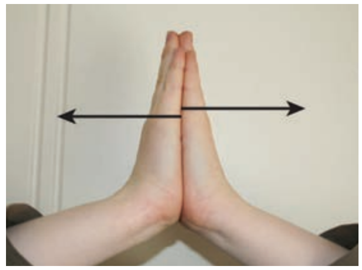
Write your ideas:

In this reading, you will learn about another force, one that is very important in many everyday phenomena. This force is friction. Friction is a force that helps to determine the winner in a game of tug-of-war.

What Is Friction?

In previous lessons, you learned about contact forces that pull or push things. Some contact forces pull downward, like a weight pulling down on a spring. Some push upward, like a table pushing up a book that is sitting on it. Some contact forces push or pull sideways, like pushing or pulling a wagon. You have also learned that all forces come in pairs, and those pairs act in opposite directions. Like all other forces, friction comes in pairs that act in opposite directions.

However, unlike many other contact forces, these forces act in parallel to the contact surface rather than perpendicular to them.



Pairs of contact forces are acting perpendicularly to the contact surface.

A pair of contact forces is acting in parallel to the contact surface.

Give an example of a situation where friction forces are involved.

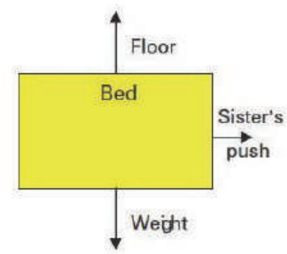
What Makes it Difficult to Move Furniture?

When most people think of friction, they think of something that slows down motion or makes things stop. Friction does both of these, but friction also affects objects even when they are not moving.

For example, imagine that your little sister wants to move her bed from one corner of the room to the other. She gives the bed a light push, but the bed does not move. She gives it a stronger push, but it still does not move. She gives it her strongest push, and still nothing happens. She calls you for help. Only when both of you push together as hard as you can, does the bed finally start to move. Why? Why did the bed not move when your sister pushed it by herself? What kept it from moving?

What made it move when you pushed together?

Imagine that your teacher asked a student in your class to draw a free-body diagram showing the forces acting on a bed when someone is pushing it but it does not move. The bed is motionless. Look at the student's drawing. Do you agree with it? Explain your ideas.



You learned that when forces that act on a motionless object balance each other, the object remains motionless. No motion begins. Since the bed does not move up or down, we know that the upward force the floor applies to the bed must equal the force of gravity pulling the bed down. The free-body diagram shows that correctly. According to the diagram, the bed should begin moving to the right because the force acting on it to the right is not balanced by a force to the left. Since you know that the bed did not move, there must be a force to the left. This force pushing to the left is friction. Friction balances the push to the right on the bed and keeps the bed from moving. If the bed does not move, it means the friction acting on it must balance the force of your sister pushing the bed. The diagram is not correct.

Correct the student's free-body diagram by changing what you think should be changed. Explain your change(s):

When an object is motionless, it can be difficult to recognize the forces that are acting on it. One way to realize that forces like gravity and friction are acting on an object is by thinking what would have happened if these forces were not there. For example, if the force of gravity did not act on a motionless bed, the bed would start floating in the air with the lightest touch.

What would have happened if friction did not act on the bed while your sister was pushing it?

How May Friction Be Reduced?

There are ways to reduce the friction between an object and a surface. For instance, if you wanted to reduce the friction between a piece of furniture and a floor, you could wax the floor to make it smoother. You could also attach wheels to the furniture. Imagine the bed in the previous example was on wheels. Would it be hard to move? The friction between a bed on wheels and the floor is much smaller than the friction between the same bed without wheels and the floor. The friction resisting the bed's motion is smaller when the bed is on wheels, so moving this bed across the floor requires a smaller force.

Look again at your corrected free-body diagram for a motionless bed. In order for the bed to start moving forward, what needs to be greater, your sister's pushing force or the friction?

Draw a free-body diagram representing the forces that act on the bed when you and your sister push it together and it starts moving. Remember that longer arrows represent greater forces.

Draw a free-body diagram representing the forces that act on a bed on wheels when your sister is pushing it by herself, making it start moving.

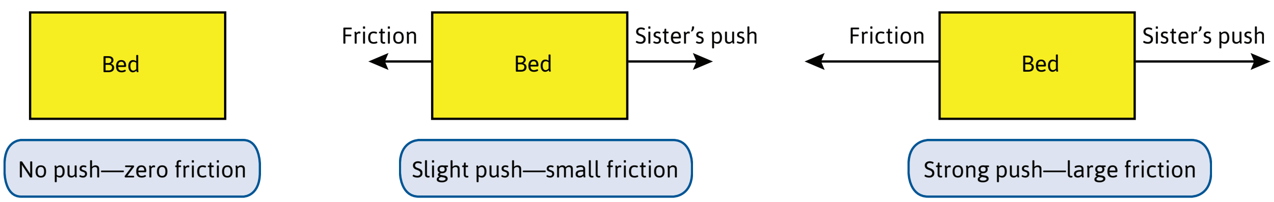
Would the free-body diagram look any different if instead of attaching wheels to the bed, you waxed the floor? Explain your ideas.

Why did the bed not move when your sister tried to move it on her own? Use the terms force and friction in your answer.

Why did the bed begin moving when you and your sister pushed together? Use the terms force and friction in your answer.

What Makes Friction Change?

The strength of the friction force between two objects is not constant. In the example of pushing the bed, the friction between the bed and the floor can change. It changes in response to the size of the force that is pushing the bed. When no one is pushing the bed, the friction is zero. You might be tempted to say that there is no friction, but it is scientifically correct to think that the friction force is zero. When your little sister slightly pushes the bed, the friction is slightly larger; it equals the size of the pushing force, keeping the bed from moving. When your sister pushes the bed strongly, the friction increases again. It increases to balance your sister's push, keeping the bed from moving.



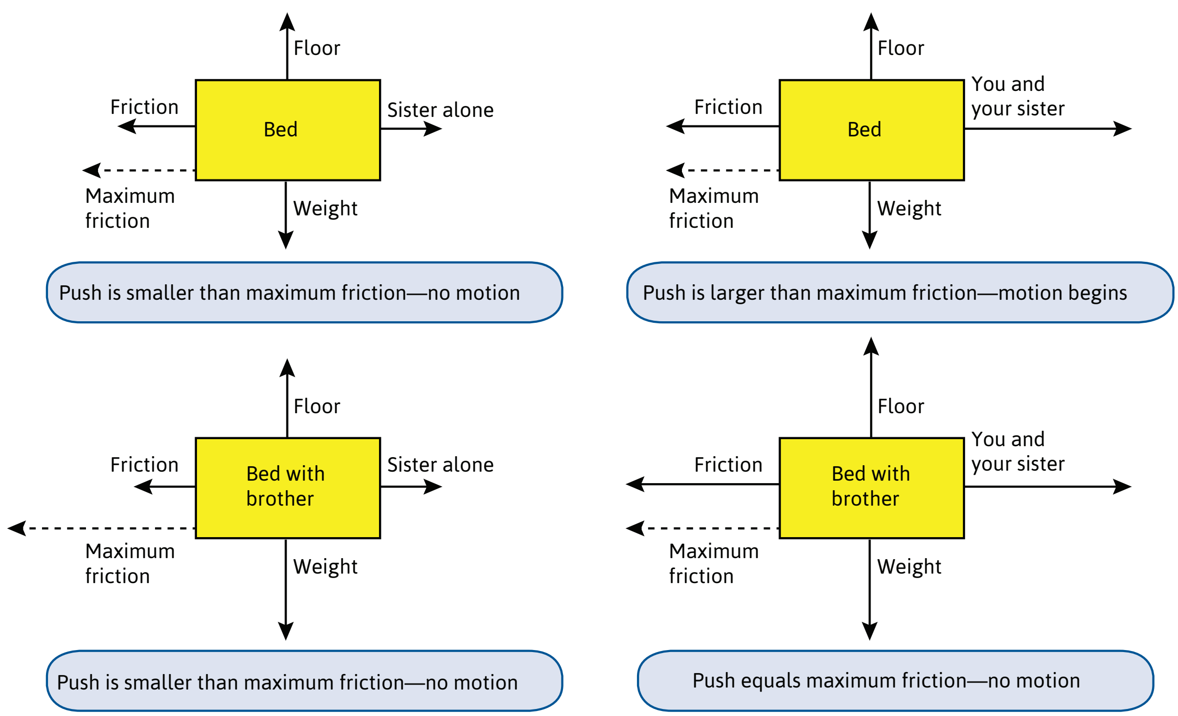
Once you join your sister, the push force becomes so great that the friction can no longer increase enough to balance it. There is a limit to how big friction can get. When friction reaches its limit, it cannot increase anymore. If the push force is greater than the maximum strength the friction can have, the bed will start moving. Strength of the friction changes from zero to a maximum value according to the push force on the bed. When the push force on the bed is greater than the maximum value of friction, the bed starts moving.

What Determines the Maximum Strength of Friction?

One way to change the maximum strength of friction is to change the object you want to move (attaching wheels to the bed) or changing the surface on which you want to move it (waxing the floor). If you attach wheels to the bed, a lighter push will make it move. That is because the maximum friction of a bed on wheels is smaller than the maximum friction of a non-wheeled bed. A smaller force is enough to overcome the maximum friction possible and to make the bed start moving. Friction also changes in response to other forces acting on the object. If, for example, your older brother sat on the bed while you and your sister were trying to push it, you would have had a harder time trying to move the bed.

In that case, you and your sister would have had to push even harder to make the bed start moving. Why? You would be trying to push both the bed and your brother, which is now more weight than just the weight of the bed. The increased weight increases the maximum strength the friction can have, making it harder to overcome it.

The following free-body diagrams might help you understand this concept.



Look at the free-body diagram at the top left. It represents your sister pushing the bed by herself without your brother on it. The maximum strength the friction can have is not so large because the bed does not weigh so much. Nevertheless, the bed will not move because the strength of your sister's push is smaller than the maximum friction. In the free-body diagram on the top right, the bed weighs the same as before, so the maximum friction is the same; but because you help your sister, the force both of you apply is greater than the maximum friction and enough to make the bed start moving. If your brother decides to sit on the bed, the weight you need to push is larger, making the maximum friction possible also larger (the lower free-body diagrams). When the maximum friction is so great, the same force you and your sister applied before is not enough anymore to make the bed start moving.

Revising the Game of Tug-of-War

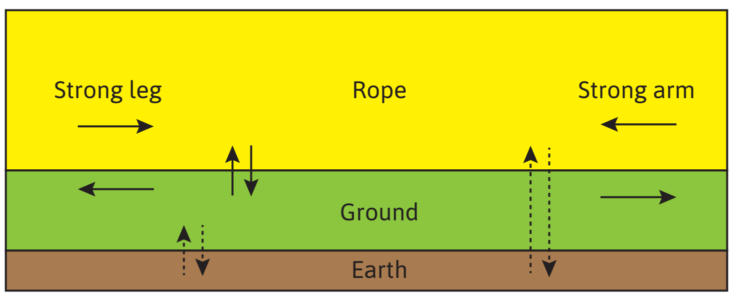
How does everything you learned in this reading explain who will win a tug-of-war? By now you have probably realized that it is not only the pulling of the rope that counts. Friction plays an important role as well. If you are curious to better understand how tug-of-war works and who wins it and if you are up for a challenge, read the following Reading You will learn more about it there.

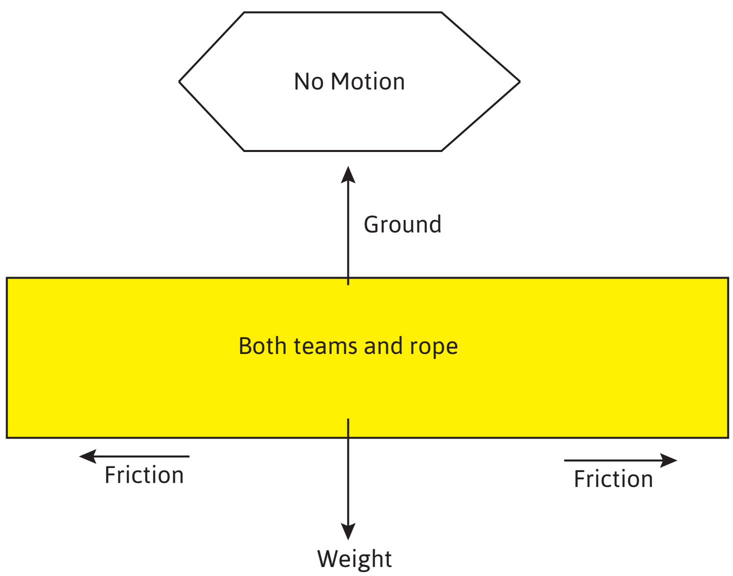
In this reading, you learned about friction that acts on motionless objects and keeps them from moving. How might friction be involved in making a moving object stop moving? You will explore this in the next lesson.

Lesson 4 Reading Two: Who Will Win a Tug-of-War?

Getting Ready

Remember the strong-leg and strong-arm tug-of-war teams from the previous reading? In that reading, you were asked to explain why the strong-arm team won. You may have answered that the strong-arm team won because they pulled the rope harder than the strong-leg team. This is true, but it is not the complete answer. In this reading, you will learn more deeply about the forces involved in a tug-of-war and why the strong-arm team really won.



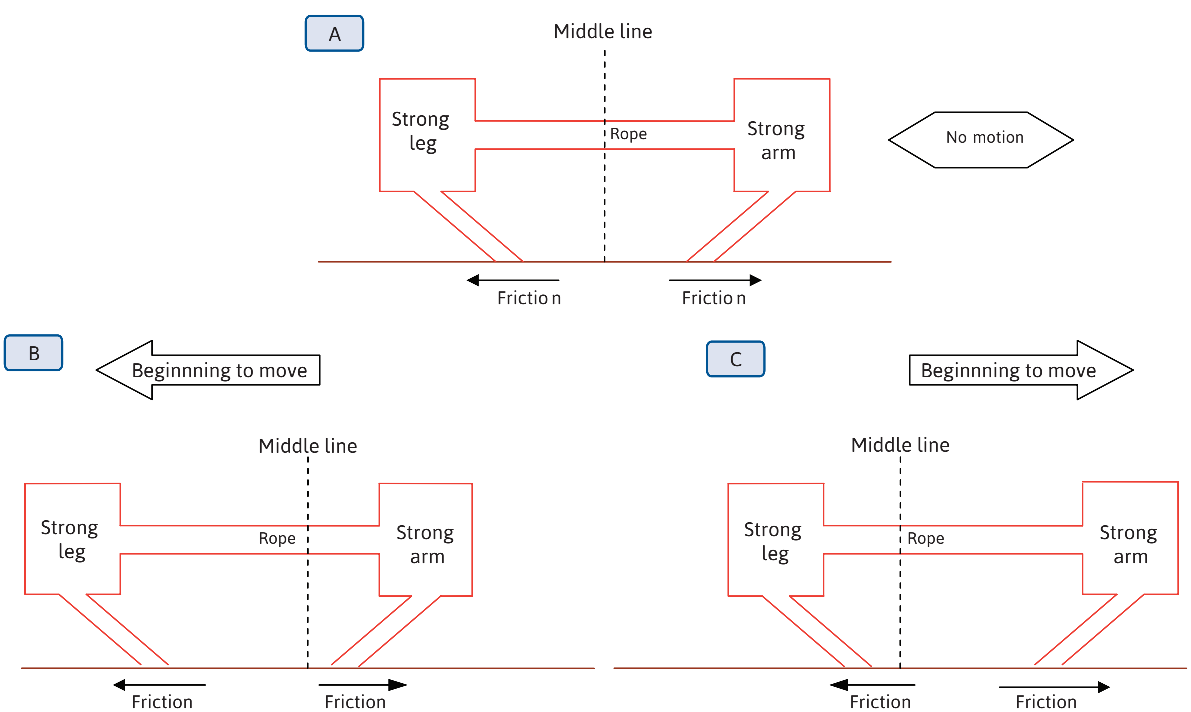


In the previous reading, you learned about friction, which stops things from moving. You analyzed how friction makes it hard to push a bed, what affects the magnitude of friction, and what determines its maximum strength. These understandings might have helped you realize that pulling the rope in a tug-of-war is not enough; in order to win, a team needs to overcome the other team's friction with the ground.

In the Beginning

Let us go back to the beginning of the competition. Both teams are at rest. Both teams pull the rope applying the same force on it. The rope does not move. This situation is described in the model and in the following free-body diagram. To make things simple, because they move together to the left or to the right, let us consider both teams and the rope together as a single component.

According to the free-body diagram, which forces act on both teams and rope before motion begins and in which directions?



What is the relation between these forces when the teams do not move?

Strong-Leg Team Is Winning

As long as both teams tightly grasp the rope, and as long as the rope does not slip in their hands, the teams do not move relative to each other. They move together as one object either in the direction of the strong-arm team or in the direction of the strong-leg team. In this situation, motion will begin only if one team manages to drag the other team across the ground.

Look at the free-body diagrams. Which forces act horizontally on both teams and rope? What forces may affect the dragging of one team by the other?

The only horizontal force acting on the teams and rope is friction. Thus friction is the only force that can cause the teams and rope to move to either side. If the friction between both teams and the ground is equal, there will be no dragging (Condition A); but if the strong-leg team manages to produce greater friction with the ground than the strong-arm team, the strong-leg team will drag the strong-arm team toward it and the strong-leg team will win (Condition B).

The Effect of the Rope

How does the pulling of the rope affect all this? If we consider both teams and rope as one component, the pulling of the rope acts within this component; it does not act on it. You learned before that only forces acting on a body can make it start moving. Assuming that the rope does not slip out of one team's hands, the pulling of the rope cannot determine who will win a tug-of-war.

What do you think will happen if a tug-of-war is held while the competitors sit on wheeled carts?

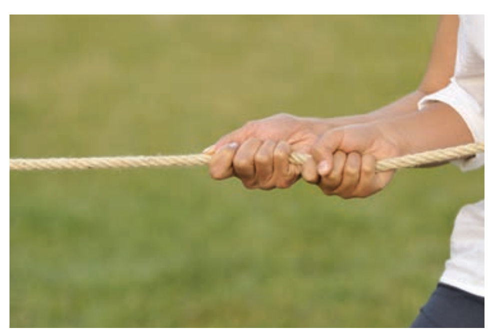
The Role of Friction

Today there is an international federation for tug-of-war, which holds world championships in this sport. Like in many other sports, professional playing is based on some knowledge of the basic laws of physics. Professional tug-of-war players know that friction is crucial for winning, and they know what they can do to increase it.

In tug-of-war, how do you think it is possible to increase friction between the players' feet and the ground?

Professional tug-of-war players know that friction is highly affected by the roughness of the surface on which they are playing. The rougher the surface, the greater the maximum friction it can apply. This is usually not a factor players can control, since both teams play on the same surface. What makes a difference is how players take advantage of the surface (e.g., what shoes they wear). Players add studs to the bottom of their shoes in order to increase their friction with the ground. There are also certain positioning and footwork, which allow the players to lock their feet and burrow them into the ground, thus increasing the maximum friction.

Do you think heavier players have an advantage in a tug-of-war? Explain. To fully answer this question, revisit Lesson 4 Reading One and refresh your memory about what determines the maximum strength of friction.



Strong-Arm Team Is Winning

The friction between the teams' shoes and the ground determines who will win the tug-of-war, only as long as the rope does not slip from any team's hands. If, for example, the strong-leg team lets go of the rope, even though their maximum friction with the ground may be greater than the strong-arm team's friction, the strong-leg team will lose the competition. In order to win a tug-of-war, it is not enough to have lots of friction with the ground. One also needs to have a very tight grip on the rope. That means that an additional friction force is involved—the friction between the hands of the players and the rope. The greater the maximum value of this friction is, the smaller are the chances that the rope will slip from the players' hands. How can players increase the friction between their hands and the rope? They can achieve this by pushing hard on the rope (increasing the weight of the hands on the rope) and by wearing gloves, which increases the roughness of the hands.

So Who Wins?

Winning tug-of-war is determined by two sets of friction forces—friction between the players' feet and the ground, and friction between the players' hands and the rope. Since there is a limit to how much a team can increase its friction with the ground (other than using heavy players and sticking studs on their shoes), the best way to increase their chances of winning is by strengthening their hands and arms, which will allow them to grip the rope harder and increase their friction with it.

If you were to compose a tug-of-war team, which players would you prefer to include—people with strong arms but weak legs, people with weak arms but strong legs, heavy people, or light people? Explain.

Activity 5.1: A Book that Stops Moving

What Will We Do?

We will examine what makes things stop by investigating a book sliding across a table and stopping.

Procedure

Gently push a heavy book across your table, not so hard that it falls off the end; the book should stop on its own. Draw two free-body diagrams of the book—one before it starts moving, while you are pushing it, and the other one while it is moving and your hand is no longer touching it. If it is difficult for you to draw the free-body diagrams without first constructing a model of the entire system, draw a model of the system and then extract the free-body diagrams of the book from it.

☐ a. What are the differences between the two free-body diagrams?

Use a force probe to gently push the book horizontally, slowly pushing harder and harder until the book starts to move. While the book is moving, read on the force probe how hard you had to push before the book started moving, and compare this to how hard you had to push to keep the book moving.

☐ b. Did you have to push harder to get the book moving or to keep it moving?

I had to push harder to get the book to start moving than I did to keep it moving.

☐ c. Look at the free-body diagram of the book before it started moving. What will happen to the book if the static friction acting on it is equal to the force of the force probe pushing the book? Explain.

The book will be in equilibrium, and it will remain at rest.

☐ d. Can the static friction on the book be greater than the force the force probe applies to the book? Explain.

No, the static friction can never be greater than the force of the force probe pushing because the static friction arises in order to keep the book motionless. That can only happen if the book remains in equilibrium, so the static force has to be equal to the force of the force probe pushing the book.

☐ e. Can the force the force probe applies to the book be greater than the static friction that acts on it? Explain.

Yes, the static friction has a maximum value. If the force of the force probe is greater than this value, the book will start moving and the static force will disappear to be replaced by dynamic friction.

☐ f. How many horizontal forces act on the book while it is sliding along the table and the force probe is not touching it? Are these forces balanced? Explain.

While the book is moving, only one horizontal force acts on it, the dynamic friction with the table. The force probe no longer applies a force to the book because it does not touch it. Since there is only one horizontal force, it cannot be balanced.

☐ g. Does the dynamic friction on the book act in the same direction in which the book is moving or in the opposite direction?

Dynamic friction always acts against the direction in which an object is moving relative to the surface on which it is sliding.

☐ h. How does the dynamic friction affect the book's motion?

Since the friction acts against the direction in which the book is moving, it wants to stop the book, so the book slows down until it stops.

Making Sense

1. What can you conclude about the relationship between forces and motion stopping?

Activity 5.2: Recoil in the Magnetic Cannon

What Will We Do?

We will investigate the Magnetic Cannon by closely observing the part of the device that does not fly out.

Procedure

Focus on the assembly, which is the name for the collection of ball bearings and magnets that remain behind. Fire the cannon several times, each time watching to see what happens to the part of the cannon that does not go flying, and make sure that the behavior you see is consistent.

☐ a. What happens to the assembly when the last ball shoots out?

It moves backward, in the opposite direction to the ball flying out. It moves a short distance and then stops.

☐ b. Draw a free-body diagram of the assembly at the moment that the cannon fires a ball. If you need some help, look at the free-body diagram you made of the shooting ball in Activity 3.3.

☐ c. What makes the assembly move backward?

Two horizontal forces act on the collection of balls and magnets—the force of the last ball pushing back and friction with the table. The force of the last ball is the only force that acts in the direction in which the collection of balls and magnets begin to move, so it must be the cause for them moving backward.

☐ d. Which force is greater—the force that makes the assembly recoil or the force that makes Ball E shoot out?

Since these forces are paired to each other, according to Newton's third law, they must be equal in magnitude.

☐ e. Why does the assembly recoil only a short distance and then stop?

When the collection of balls and magnets moves backward, they are subjected to only one horizontal force—the friction with the table. The force of Ball E no longer exists because Ball E is no longer in contact with the assembly. The friction with the table causes the assembly to slow down and stop.

Lesson 5 Reading One: What Affects How Quickly Something Stops Moving?

Getting Ready

One day in 2006 at a beach in Australia, 2,921 people gathered to throw 55,000 water balloons into the air. They broke the world record for the number of people throwing water balloons and also raised money for a local charity. Many people got wet as thousands of the balloons popped when they hit the ground. The largest water balloon fight consisted of 8,957 participants and was achieved by Christian Student Fellowship at the University of Kentucky (USA) in Lexington, USA, on 27 August 2011. 175,141 water balloons were used during the fight.

Some balloons did not pop. Why?

In this reading, you will learn how forces determine whether a water balloon will pop when it hits the ground.

Try This at Home

You could try this yourself with a couple of balloons, some water, and a place that can get wet (outdoors or in your bathtub). Fill a balloon with water until it is stretched, but not too much. Tie the balloon so it is sealed. Gently throw the balloon at the ground (or the floor of the tub). Did anything happen to it? Keep throwing the balloon harder and harder until it pops. If you cannot make it pop, you might need to add more water.

Why do you think the water balloon did not pop when you threw it gently? Why did it pop only when you threw it harder?

In class, you saw that moving objects stop because a force is applied to them opposite to the direction of their motion. You investigated how books in motion stop because of friction. Did you ask yourself whether the strength (magnitude) of the stopping force mattered? How does the magnitude of a force affect the way an object stops? This reading will use three examples to show how the strength of a force affects the way an object stops—air hockey, baseball, and a circus trapeze.

Air Hockey

A typical air hockey table consists of a large, smooth playing surface with tiny holes in it. A small pump blows air through the tiny holes, creating a cushion of air on the surface. Pucks slide easily on the cushion of air because the air reduces the amount of friction between the table and the puck.

Imagine that as the puck moves across the table, the pump was suddenly turned off and there was no more air cushion. What would happen to the puck?

Since you learned in class that forces make objects stop moving, how can you use forces to explain what happens to the puck when the air cushion is no longer there?

If the air cushion is no longer there, do you think it is correct to say that the puck stops by itself? Explain your ideas.

What do you think would happen to the puck if, while it was gliding across the table, the pump was not shut off completely, but only turned down a bit so that less air came out of the tiny holes in the tabletop? Would it stop as quickly as it stopped when the air was turned off completely? Explain your ideas.

Magnitude of Forces

The magnitude of the force that stops an object's motion affects whether the object will stop quickly or slowly. Weak forces, such as the friction between the puck and the table when the air is blowing at medium strength, cause objects to stop gradually. Strong forces, such as the friction between the puck and the table when the air is shut off, cause objects to stop quickly.

According to Newton's third law, every force is paired to another force of equal magnitude acting in the opposite direction. If you think about the water balloon example, that means the force the balloon applies to the floor when it hits has the same magnitude as the force the floor applies to the balloon. When a water balloon hits the floor gently, the force the balloon applies on the floor is small. That means that the floor also applies a small force to the balloon. The force that the floor applies to the balloon is what makes the balloon stop moving. Since this stopping force is small, it makes the balloon stop its motion gradually, not stretching too much. It may even bounce a bit. When the water balloon hits the floor hard enough, the force the floor applies to it is much greater, causing it to stop quickly and causing it to burst.

A Baseball Catch

Baseball players wear special gloves to protect their hands when catching a baseball. Think about why this is so.

When do you think the baseball stops more gradually—when it is caught by a bare hand or when it is caught by a hand wearing a padded glove?

What does that tell you about the force that is applied to the ball that makes it stop? Is it smaller with the glove or without the glove? Why?

What does that tell you about the force the ball applies to the player's hand? Is it smaller with the glove or without the glove? Why?

When you catch a baseball with a padded glove, the padding in the glove provides cushioning. This makes the ball slow down and stop gradually, as your hand in the glove applies a relatively small force to the ball. This also means that the ball applies a smaller force to your hand, protecting your hand. When caught barehanded, the ball stops rapidly, requiring a greater force, meaning a greater force is applied to your hand.

The pocket of the glove is the best place to catch the ball because it has the most cushion; the whole glove bends and changes its shape when the ball is caught there. The worse place to catch the ball is in the palm, where there is the least padding.

Falling from a Circus Trapeze

Have you ever been to a circus? Or have you seen a trapeze act on television? In a trapeze act, acrobats fly in the air from one bar to another, high above the ground. A safety net underneath the trapeze catches an acrobat if he or she makes a mistake and falls.

Consider what you have learned about forces in this reading. In the following space, explain how a safety net can keep acrobats from breaking their bones.

Summary

In this reading, you learned why some objects stop quickly while others stop slowly. You read about a few examples showing that when a strong force is applied to a moving object against its direction of motion, it causes it to stop quickly. A weak force causes the object to stop gradually.

Activity 6.1: Graphs that Show When a Ball Moves

What Will We Do?

We will learn how to draw and read a graph that describes what happens when an object moves.

Procedure

☐ a. Your teacher will demonstrate Newton's Cradle to the class. Make a simple drawing that shows when Ball A (the ball that the teacher lifted and then dropped) is moving and when it is not moving. It is not important to describe how much the ball is moving, just if it is moving or not.

☐ b. Use what you learned about making a graph that describes the motion of the ball that was dropped to make another graph. This graph should depict the ball at the other end of the cradle (Ball E)—the one that is motionless when Ball A is swinging, and is swinging when Ball A is motionless. This new graph should look very much like the first one, but with some changes.

Here are some things you should think about as you draw your graph:

- ☐ a. Does the ball begin motionless, with the first line a not-moving line?
- ☐ b. Does the first not-moving line last 0.5 seconds?
- ☐ c. Are all the other lines equally long and do they last one second?
- ☐ d. Are there vertical and horizontal axes?
- ☐ e. Are the axes titled Time and Motion?
- ☐ f. Are there units next to the horizontal axis?
- ☐ g. Are there numbers at regular distances along the horizontal axis?

Activity 6.2: Graphs that Show How a Ball Moves

What Will We Do?

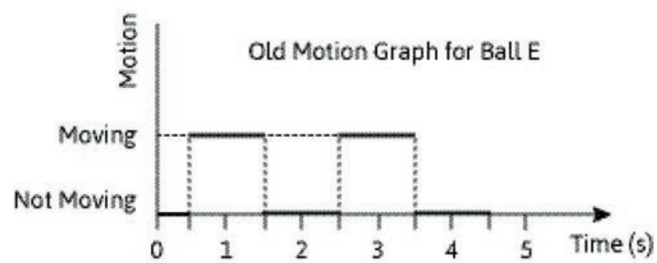
We will learn how to draw and read graphs that describe how an object moves.

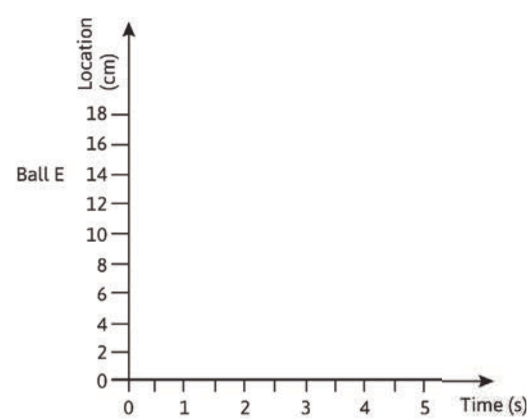
Procedure

Your teacher just showed you how to make a motion graph for Ball A (the ball that the teacher lifted and then dropped) that shows how the ball moves, not just when it moves.

Working together with a partner, draw a similar kind of graph for Ball E, the ball at the other end of the cradle. You will need two items:

- The graph you made in Activity 6.1 that shows when Ball E moves
- A pair of axes for the new graph you will draw





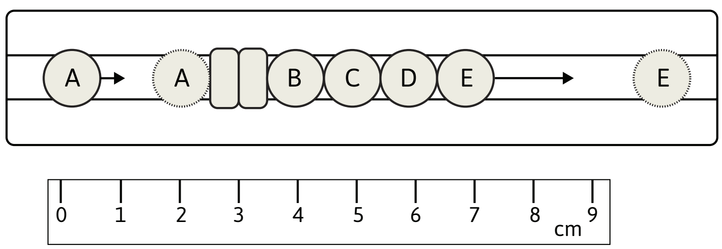
Activity 6.3: Motion Graphs for the Magnetic Cannon

What Will We Do?

We will use what we have learned to draw two motion graphs of the Magnetic Cannon—one for the ball that activates the cannon, the other for the ball that shoots out.

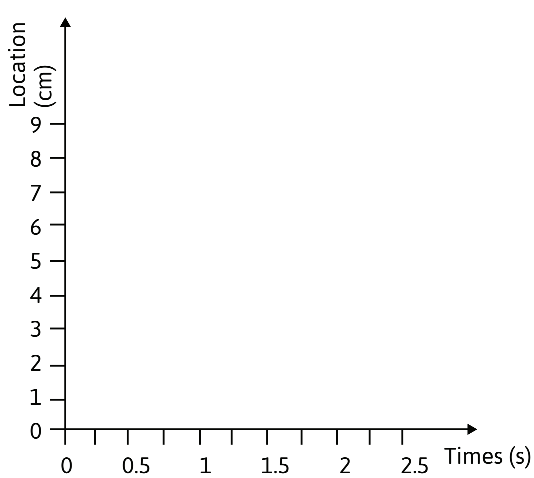
Procedure

The drawing represents a Magnetic Cannon next to a ruler.



When drawing the graphs, assume that you started measuring time from the moment that the entering ball (Ball A) is released and that it took this ball one second to reach the magnets. Make both graphs on the same pair of axes.

Where is Ball E located one second after it shoots out?



Making Sense

1. What kind of motion is depicted by a horizontal line in a motion graph?

2. What kind of motion is depicted by a line in a motion graph with a small slope?

3. What kind of motion is depicted by a line in a motion graph with a steep inclination?

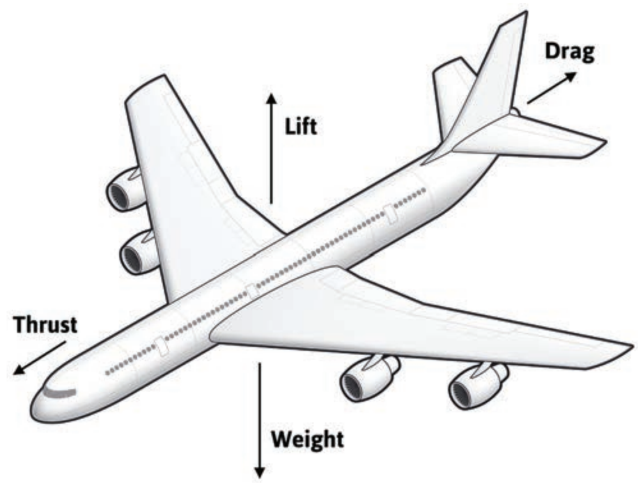
Activity 7.1: Changing Speed

What Will We Do?

We will analyze three objects moving in different ways to determine the relationships between the forces acting on them.

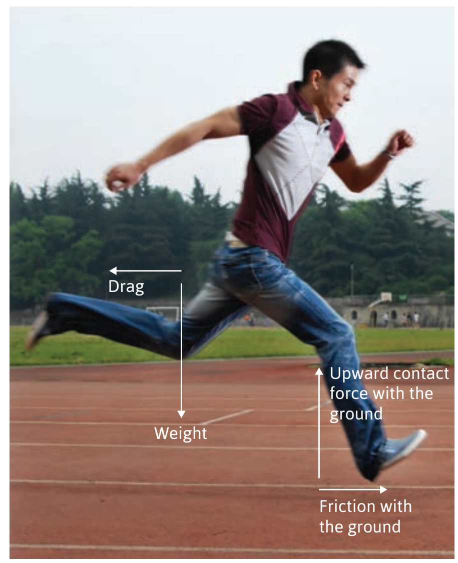
Procedure

☐ a. Every airplane has at least four different forces acting on it: the thrust of the engines that push forward, the drag (friction) of the air that pushes backward, its weight that pulls it down, and the lift on the wings that push upward. Assume that the plane in the drawing is slowing down while flying horizontally. Which of the four forces shown is greater than others? Which are equal to others? Explain your answer.



☐ b. A skydiver has opened her parachute and is slowly falling to the ground at a constant speed. What are the two forces that are acting on the skydiver? Add them to the photograph. Also, what is the relationship between these two forces? Explain.

☐ c. A runner is speeding up as he nears the finish line. Four different forces act on the runner, two vertical and two horizontal. What are these four forces? Add them to the photograph. Also, what is the relationship between these forces? Explain.



Homework 7.1: Force and Motion

A sailboat is floating across a lake. Four forces act on the boat: its weight, the buoyant force (the contact force with the water that pushes the boat up), the forward force of the wind, and the backward drag of the water. At a given instant, the force of the wind on the boat and the drag with the water are both equal to 100N, and since the lake is perfectly smooth, the boat moves across the water without bobbing up and down.

1. What is the relationship between the boat's weight and the buoyant force acting on it?

2. Does the sailboat move at a constant horizontal speed, does it speed up, or does it slow down? Explain.

3. The wind weakens a bit, but the sailor on the boat does not want it to move slower; so she turns on an overboard engine to help push the boat forward. What pushes the boat forward, the engine or the water? Explain your ideas.

4. If the force of the wind is now only 25N, what is the force the engine must push on the water to keep the boat moving at the same speed as before? Explain your ideas.

Activity 7.2: Changing Direction

What Will We Do?

We will analyze the way a ball moves when being pushed or pulled from the side.

Procedure

Gently roll a heavy ball across your table and then, while it is rolling, tap it on its side. Repeat this a few times, each time tapping the ball in a different direction: perpendicularly to its original direction of motion, slanted against its initial direction, and slanted so that the tap both pushes the ball forward and to the side.

☐ a. Does the ball always change direction after being tapped? Explain.

☐ b. Does the direction in which the ball was tapped (perpendicularly to its original motion, slanted backward or slanted forward) have any effect on the direction in which the ball changes direction?

☐ c. Repeat the former procedure using a ball bearing and a single magnet. Instead of tapping the ball bearing, just bring the magnet close to it from the side as it rolls. Does the ball change direction after passing near the magnet? Explain.

☐ d. Repeat this procedure using two magnets. Put the magnets on different sides of the rolling ball or on the same side. In which case do the magnets have a greater effect—when they are on the same side of the rolling ball or on different sides? Explain.

Activity 8.1: Revisiting and Summarizing the Scientific Principles

What Will We Do?

We will revisit and summarize the Scientific Principles we have learned during the unit.

Procedure

Your teacher will list the scientific principles learned in the unit. List the phenomena that you investigated that provide evidence in support of some of these principles.

Principle 1: All forces come in pairs, in opposite directions.

☐ a. List the supporting phenomena:

Principle 2: The start and end of motion is always cause by forces.

☐ b. List the supporting phenomena:

Principle 3: Forces that are applied to an object in opposite directions counteract each other.

☐ c. List the supporting phenomena:

Principle 4: Forces that are applied to an object in the same direction reinforce one another.

☐ d. List the supporting phenomena:

☐ e. Summarize principles 3 and 4 as one.

☐ f. Why does a parachutist not fall, as in free fall? Add arrows to the drawing if it helps clarify your answer.

Principle 5: An object's motion is influenced only by the forces that are applied to it, not by the forces it applies to others. This principle has been used throughout the unit.

☐ g. List the supporting phenomena:

Principle 6: For every force an object applies, there is an equal and opposite force acting on the object.

☐ h. Summarize principles one and two as one.

☐ i. When a hammer hits a nail, what force makes the nail dig into the wood?

☐ j. What makes the hammer stop when it hits the nail?

☐ k. What is the relation between these two forces?

Principle 7: An object will continue to remain at rest or move at a constant speed and in a straight line unless it is subjected to unbalanced forces.

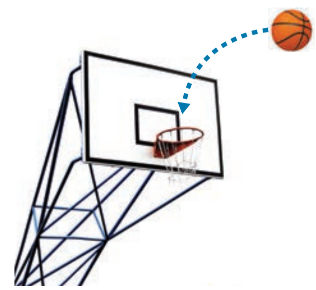
☐ l. List the supporting phenomena:

Principle 8: Unbalanced forces acting on an object change its speed or direction of motion, or both.

☐ m. List the supporting phenomena:

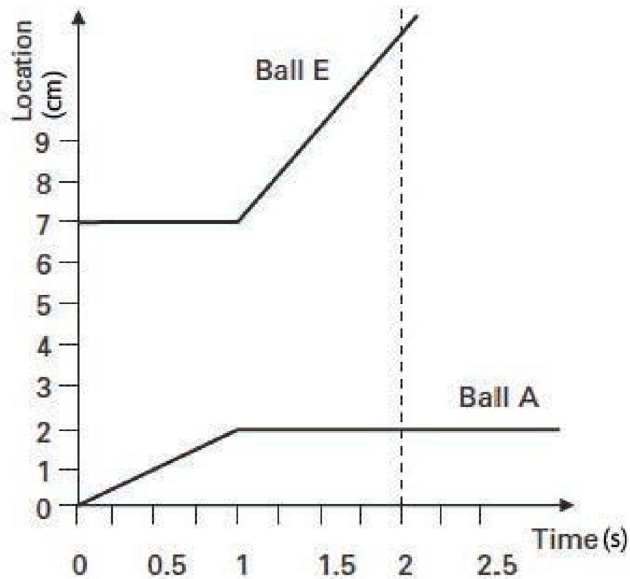
Principle 9: An object will change its speed of motion or direction or both if it is subjected to unbalanced forces, otherwise it will continue to remain at rest or move at a constant speed in a straight line.

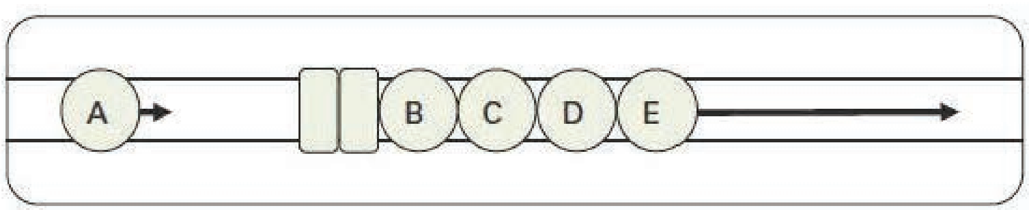
☐ n. When you throw a basketball at the basket, why does it move in an arc rather than in straight line?



Homework 8.1: Motion Graph

The following graph is the motion graph of the Magnetic Cannon that was developed in Lesson 6. This graph is the starting point for the next activity in which you will use the principles summarized in today's lesson to give an explanation of how the Magnetic Cannon works.





Closely observe the graph and drawing and try to answer the questions that follow.
During the first second:

- Was each ball moving or motionless?
- Which forces acted on each ball?

- Did these forces reinforce or counteract each other?

Repeat these same questions for the balls' motion after one second.

- Was each ball moving or motionless?
- Which forces acted on each ball?
- Did these forces reinforce or counteract each other?

Activity 8.2: Can We Explain the Behavior of the Magnetic Cannon?

What Will We Do?

We will use scientific principles to explain the behavior of the Magnetic Cannon.

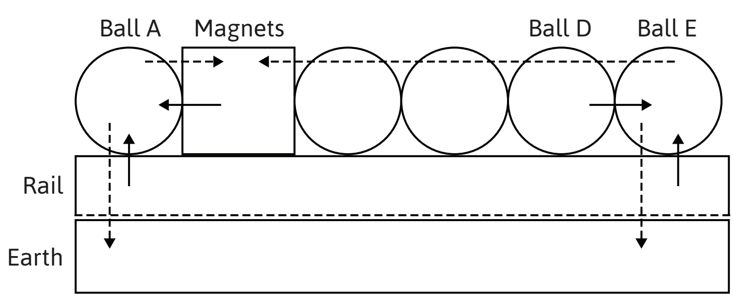
Procedure

Analyze the motion of, and the forces acting on, various components of the Magnetic Cannon, with the goal of explaining how the cannon works.

In the last lesson, the following scientific principle was summarized: An object will change its speed of motion or direction or both if it is subjected to unbalanced forces; otherwise it will continue to remain at rest or move at a constant speed in a straight line.

- ☐ a. What does this principle have to say about the forces that were applied to Ball A and Ball E at the moment they changed their motion—in other words, the moment at which Ball A collided with the magnets and Ball E shot out?

- ☐ b. Using the following diagram, draw two free-body diagrams, one for Ball A and one for Ball E.



☐ c. Why do Balls A and E move only horizontally and not vertically?

☐ d. Ball A and Ball E are each subjected to two vertical forces. What is the relation between each pair of forces?

☐ e. Ball A was moving to the right and then stopped. Which force do you think was greater at the moment of impact—the magnetic attraction or the contact force with the magnet? Explain using scientific principles.

☐ f. Ball E was not moving; then it shot out to the right. Which force was greater at the moment of impact, the magnetic attraction or the contact force with Ball D? Explain using scientific principles.

☐ g. Which ball, at the moment of impact, was subjected to a greater magnetic force of attraction—Ball A or Ball E? Explain.

Activity 8.3: Concluding the Activity

What Will We Do?

We will explain why Ball E shoots out from the Magnetic Cannon compared to when Ball A reaches it.

Procedure

Summarize in a table what you know about forces and energy. Place a check mark in the Energy column or the Forces column for each statement.

Characteristic	Energy	Forces
It has a direction.		
An object can have it.		
One object can apply it to another object.		
One object can transfer it to another object.		
It cannot be created or destroyed.		
It always comes in pairs.		
It is transformed.		
It can be counteracted.		
It causes motion to change.		
It is useful for explaining phenomena not involving motion.		
It is useful for explaining phenomena involving motion.		

Indicate how much kinetic and magnetic energy there is to each ball of the Magnetic Cannon in each condition by writing lots, almost nothing, or very little in each cell of the following table.

☐ a. Write an explanation, using energy considerations, of why Ball E shoots out of the cannon.

☐ b. The magnet in the Magnetic Cannon attracts the ball bearings just like Earth attracts an object near it. Using energy considerations, explain why falling objects move faster as they get closer to the ground.

Appendix

Activity 1.1: Designing The Best Electromagnet

What Will We Do?

We will build and test electromagnets that can pick up and drop small metal objects. Then we will use the results of our tests to design an electromagnet that can successfully complete a challenge task.

Prior Knowledge about Magnetic Attraction

What do you already know about the forces of attraction that magnets apply to other objects?

SAFETY GUIDELINES

Do not leave the electromagnet "on" when you are not actively testing something. Leaving it "on" (battery terminals connected to the wires and switch closed in the "on" position, forming a complete electric circuit) for several minutes will cause the connections and the wires to become warm.

Touching these warm metal parts of the circuit to skin can result in small electric shocks and burns.

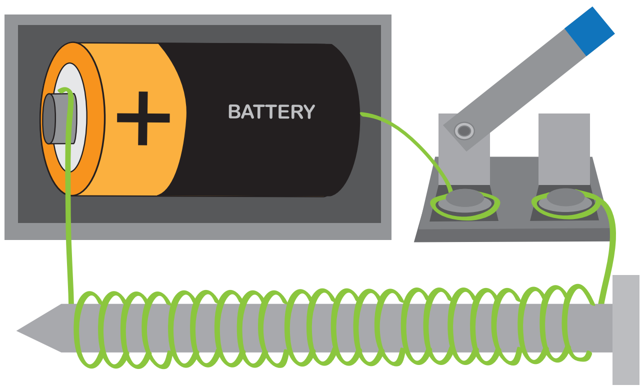
Designing an Electromagnet Part 1:

Building and Testing a Basic Electromagnet

In Part 1, you will build a basic electromagnet and observe the forces it applies on small metal objects.

Procedure

☐ a. Your teacher will provide you with materials you need to create an electromagnet like the one shown here.



☐ b. Start with a 1-m-long insulated wire. Leave about 15cm (about 6in) loose.

☐ c. Start wrapping the wire around a nail so that it forms tight coils that are closely spaced. Leave about 15cm of the wire unwrapped at the end. This should leave about 15cm of uncoiled wire free on each end of the nail.

☐ d. Connect one free end of the wire to a single-battery holder that contains a size-D battery cell.

☐ e. Connect the other free end to a switch that is open, or "off."

☐ f. Connect the other end of the switch to the other end of the battery holder using a 30-cm insulated copper wire.

☐ g. The complete circuit produces an electromagnet at the end of the nail. To operate the electromagnet, hold it by the insulated wire coils and position the end of the nail near an object. Close the switch, putting it in the "on" position.

(Careful: Do not leave the electromagnet "on" when you are not actively testing something. Leaving it on will drain the battery and cause the connections to become warm. Touching them could cause small electric shocks or burns.)

Data

Observe the force the electromagnet applies on the object. What kind of force does it apply? What kinds of objects can the electromagnet pick up? What happens when you turn the electromagnet off?

Once your electromagnet is complete and you have practiced operating it, it is time to test it. Design tests to answer the following types of questions:

a) How far away from an object can the electromagnet be and still apply a force that will pick up the object?
b) How many staples, straight pins, or paperclips can the electromagnet pick up at one time?
c) How does placing objects in a paper envelope affect how well the electromagnet attracts the objects?

Describe the tests that you have designed and record your data below.

You will be using the electromagnet to complete a challenge task assigned by your teacher. Sketch a diagram of how you will use your electromagnet to complete the challenge task.

Think about the forces at work during the task. Sketch a free-body diagram that describes the forces involved. Be sure to indicate whether forces are contact forces or forces that act at a distance.

Analyze Results

Given the data you collected in your tests, would you expect your electromagnet to be able to complete the challenge task? Explain your ideas.

Describe the force or forces that must change in order for the electromagnet to successfully complete the challenge task.

Designing an Electromagnet Part 2:

Redesigning the Electromagnet Based on Test Results

In Part 2, you will modify the basic electromagnet in two different ways. You will test each modified electromagnet to see how it differs from the basic electromagnet. Then you will use the results of these tests to design an electromagnet that can complete the challenge task.

Procedure

Assemble the modified electromagnet.

☐ a. Your teacher will provide you with a second 1-m-long insulated wire.

☐ b. Disconnect the ends of the coiled wire from the switch and battery holder. Connect the new wire to one free end of the coiled wire.

☐ c. Wrap the wire around the nail, using closely spaced, tight coils. Double over the existing coils when you run out of room on the nail. Again, be sure to leave about 10–20cm (4–8in) of uncoiled wire free on each end.

☐ d. Reconnect the free ends of the wire to the battery holder and the switch.

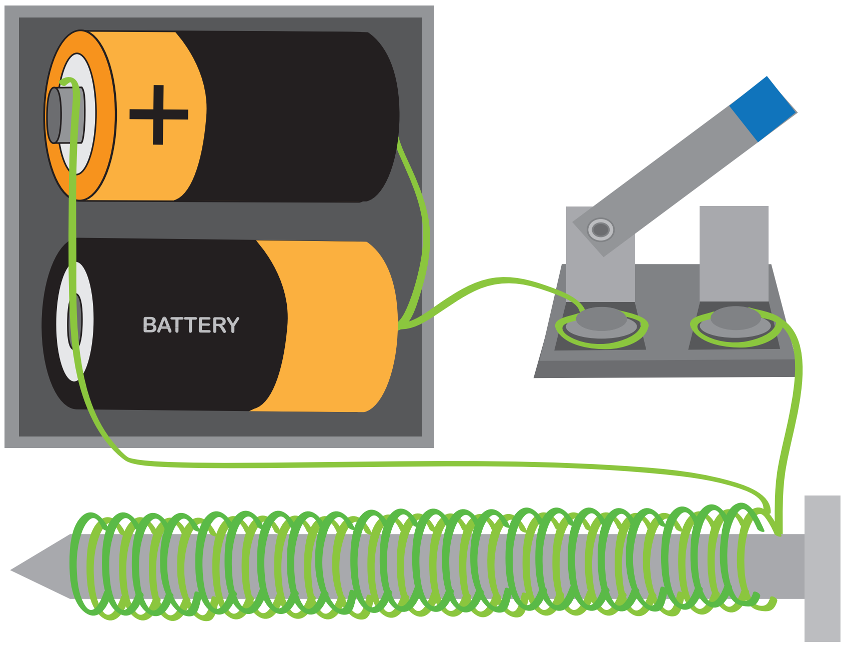
Data

Test your modified electromagnet.

Re-do the same experiments you performed on the basic design.

Compare your results. How is the modified electromagnet different? How does changing the number of coils of wire around the nail affect the strength of the electromagnet? How does it affect the number of objects the magnet can pick up (compared with the basic electromagnet)? Record your data below.

Your teacher will provide you with a double-battery holder that will hold 2 size-D battery cells. Disconnect the ends of the wire that lead to the single-battery holder. Replace the single-battery holder with the double-battery holder and reconnect the wires to complete the circuit.



Test your newly modified electromagnet according to the same experiments you performed on the basic design and the first modified design.

How is this modified electromagnet different? Can it pick up more objects than the basic electromagnet? Can it pick up more objects than the first modified electromagnet? Record your data below.

Analyze Results

Given the data you collected in your tests, do you think one of your modified electromagnets will be able to complete the challenge task? Explain your ideas.

Given the data you collected in your tests, do you think either of your modified electromagnets is strong enough to pick up even more than is required by the challenge task? Explain your ideas.

Making Sense

1. How will you redesign your electromagnet to complete the challenge task? Describe your final design below.

2. Which test results did you use to guide the design of your final electromagnet?

3. Test your final electromagnet by using it to carry out the challenge task. Did it work? How efficient was your use of materials? Should you use more materials—more batteries or more coils of wire? Or, could you have used fewer?

4. How could you modify your design again to pick up heavier packets?

Appendix Lesson 1 Reading One: How Do Electromagnets Work?

Getting Ready

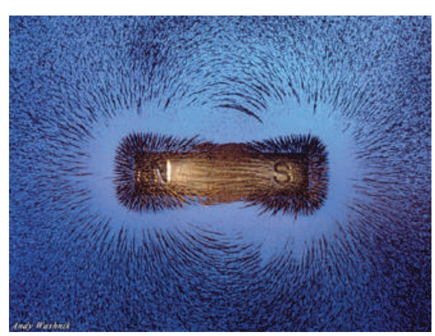
You probably experimented with magnets when you were in elementary school. 1) What do you know about what magnets do? 2) What are some examples of how magnets are used?

You are going to read about some uses of magnets that may be new to you. You will also read about magnetic fields.

You know what a magnet is, but what do you think a magnetic field could be?

Magnetic fields

Look at how this bar magnet affects the tiny bits of iron that are nearby. How would you describe what you see?

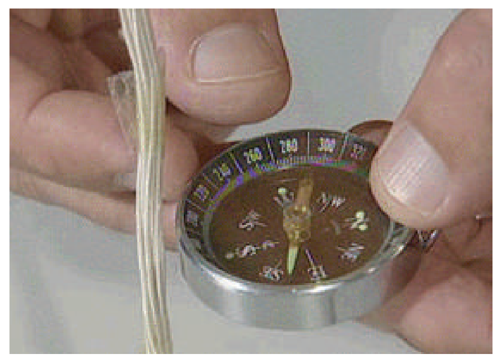


Because magnetic forces can act at a distance, the magnet does not have to touch an object to apply a pull force on that object. The magnet pulls the bits of iron toward it from many different directions. They form a pattern that spreads out from the magnet in a distinct curved shape. This shape represents the magnetic field that surrounds the magnet. A magnetic field is the area around a magnet where nearby objects are affected by the push and pull forces of the magnet. An iron object located within the magnetic field experiences a pull from the magnet and is thus attracted to it. An object located outside of the magnetic field does not experience pull forces from the magnet and is not affected by it.

Magnets tend to apply stronger pull forces at the ends of their north and south poles. Also, the strength of a pull force is stronger the closer the magnet is to the object it is attracting. These factors influence the shape of a magnet's magnetic field.

When two magnets come near each other, their magnetic fields overlap. Each magnet applies pull and push forces on the other. Their poles that are alike (both south or both north) push each other apart, and their opposite poles (one north and one south) pull each other together. Thus, two magnets that are not fixed in place tend to align with each other, or move around until the north pole of one magnet is closest to the south pole of the other magnet, and vice versa. They move around—by themselves—so that a north pole and a south pole line up together!

This effect is what makes a magnetic compass needle work. A compass needle is a magnet that can spin. Earth has a magnetic field, too. It is like the magnetic field of any magnet: It has north and south poles. A compass needle always points North because its magnetic field tends to align with Earth's magnetic field.



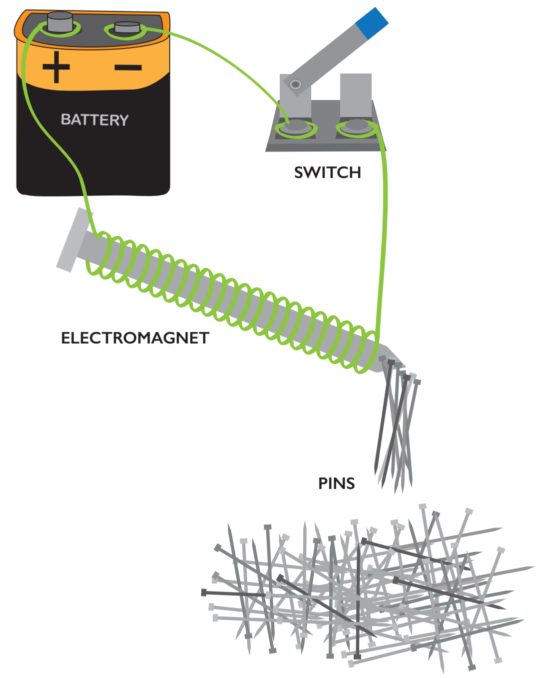
Electric currents and magnetic fields

People studying magnets and electricity noticed something interesting when a magnetic compass needle comes near a wire that is carrying an electric current. When an electric current is passing through the wire, the compass needle behaves as if the wire is another magnet. That is, if you move the compass to different positions around the wire, the needle will align itself as if it is interacting with another magnetic field. When the electricity is turned "off" and there is no electric current, the compass is no longer affected by the wire. The invisible force that acts on the needle is gone.

The effect that an electric current has on a magnetic compass needle has to do with magnetic fields. A compass needle usually is aligned with Earth's strong magnetic field. However, a wire carrying an electric current also has a magnetic field, although often a weak one. When the compass needle comes near a current-carrying wire, its magnetic field aligns with the magnetic field of the wire. However, it does so only as long as there is current in the wire. When there is no longer an electric current in the wire, the needle aligns with Earth's stronger magnetic field again, pointing North.

Building an electromagnet

You can use the magnetic field surrounding a wire that carries an electric current to produce an electromagnet. By coiling a current-carrying wire around an iron object, such as a nail, you can produce a magnetic field around the object. Like a traditional magnet, the electromagnet can attract iron objects that are located within its magnetic field. However, unlike a traditional magnet, the magnetic field is not permanent. It exists only when there is an electric current in the wire. This is useful for when you want to use a magnet whose magnetic field you can turn "on" and "off."

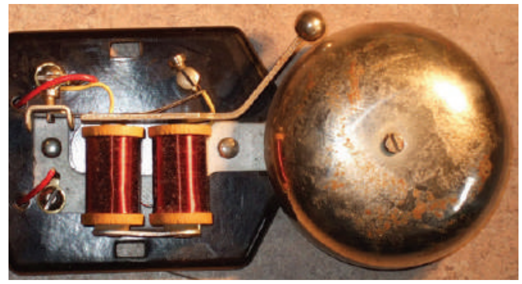


How did you turn your electromagnet "on" and "off"?

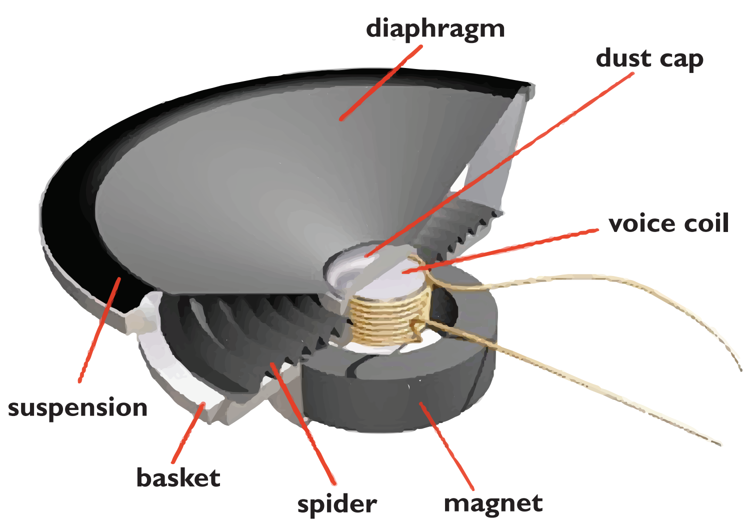
Uses of electromagnets

Electromagnets are useful for moving objects that are made of iron or steel, which is a metal mixture that includes iron. One setting where you might find a lot of steel objects is a junkyard. Many objects made of steel, such as worn-out car parts or broken pieces of building materials, may no longer be useful, but their steel material can be salvaged and recycled. Junkyard workers can use large, powerful electromagnets attached to cranes to sort, gather, and move heavy pieces of steel. Some are strong enough to pick up entire cars with the flip of a switch!

Many machines you might find around the house or your school use electromagnets to control the movement of their steel parts. One type of electric alarm bell that may ring between classes in your school uses an electromagnet to move a steel hammer that strikes the bell and causes it to ring. By producing and then removing an electric current in the electromagnet's coils, quickly and repeatedly, the hammer is pulled toward and away from the bell over and over again, thereby making a repetitive clanging sound.



When the first bell rings at school, it's time to take off your headphones or earbuds and start listening to the announcements over the loudspeaker. Did you know that both kinds of speakers are devices that use electromagnets to move their parts? Many speakers contain both electromagnets and ring-shaped permanent magnets. The magnetic fields of both types of magnets interact to make the round, vibrating part of the speaker move. And, it is the vibration of the speaker according to the current in the electromagnet that produces the sound waves that allow you to hear music or a person's voice.



Activity 2.1: Organization and Formation of the Universe

What Will We Do?

In this activity, we will act out the formation of objects in the universe, such as galaxies, stars, and planets. Then we will analyze our results to figure out how stars and planets first formed.

Procedure

☐ a. Take the "speed" card your teacher assigns you, and follow your teacher's instructions to move to your starting position.

☐ b. Before the activity begins, draw the starting positions of everyone in the class (in the Data section below).

☐ c. When your teacher indicates that it is time to begin, start walking at your assigned speed in a counterclockwise circle from your starting point. For example, if you get a green card, you will move quickly, three steps for every beat. If you get a yellow card, you will move two steps for every beat. If you get a red card, you will move slowly, only one step for every beat.

☐ d. When you approach another student in the same ring you are in, put your arms out in front of you. When you touch that student, you have joined, or accreted, to form a single, bigger object that must travel at the speed of the slower student. If you approach another student or group of students in an adjacent ring, put your arms out to the side, and if your hands touch, both students (or groups) move toward each other until your shoulders meet, and continue forward around the circle as a single object at the speed of the slower student or group. Always try to arrange yourselves into the smallest, tightest configuration possible without causing difficulty walking.

☐ e. When your teacher calls time, stop and draw the groupings of students in the Data section below.

☐ f. Your teacher may give you new instructions to repeat the activity. As you do it a second time, pay close attention to how you and your classmates interact.

Record your data. Then share results with a partner or with your group.

Data

Use the space below to draw a representation of the positions of all students in your class at the beginning of the activity.

Use the space below to draw a representation of the positions of all students in your class at the end of the activity.

Use the space below to draw a representation of the smallest, tightest configuration of students in a group of three or more.

Making Sense

1. How did the small particles (individual students) interact with each other at the beginning of the activity?

2. How did larger particles (students connected to other students) interact with other particles?

3. What would happen to the groups of students in your simulation if a much larger group of students (a single group of approximately 50 students) were added to the system?

4. What did the requirement for the groups to form compact shapes represent in the model? How did this requirement affect the shape of the larger “particles”?

5. How did this activity model the formation of planets in the solar system?

Appendix Lesson 2 Reading One: Studying the Universe

Getting Ready

Many years ago, an astronomer named Tycho Brahe was making a map of the sky, recording where each star was located. He also noted how bright, how big, and what color each star seemed to be. Telescopes were not invented; all Brahe had were his eyes. One night he noticed a new, very bright star in the sky that was not there before. It was there the following night and many nights to follow. The star was so bright it was visible even in the daytime. Brahe kept records of this new star. He recorded notes about how it appeared and how it began to fade. After 18 months, it disappeared. Brahe could not explain what he saw.

Today, we know that Brahe observed the explosion of a star that actually happened 7,500 years before he saw it. How could Brahe have seen something that happened in the past?

In this reading, you will learn about stars and other objects in the universe. You'll also be able to answer the question: "How could someone see something that happened in the past?"

Stars

Have you ever looked up at the sky at night? How many stars do you think people standing on Earth can see on a clear night? How far away do you think the nearest star is to Earth?

Most of the points of light you see in the sky at night are stars. You have probably learned that the sun is actually a star, too. The sun is a huge ball of gas that radiates light. All other stars are also large balls of gas that radiate light. However, they are much, much farther away from Earth. That is why they appear so much smaller than sun.

Stars can be different sizes, colors, and temperatures. They also last for different amounts of time. Inside the core of stars, processes take place that produce energy. That energy is released as light, heat, and other forms of radiation. Small stars usually use up their fuel slowly and, therefore, are relatively cold. On the other hand, because they use their fuel slowly, they also can last for a long time.

Star colors

When stars are relatively cold, they are a reddish color. If you have learned about infrared light, you know that different parts of a flame have different colors. The different colors are related to different temperatures. The hottest part of a fire is its blue part. The coolest part is the red. Yellow is in between. Stars are the same; their temperature determines what color they will appear to be. You can tell how hot a star is by looking at its color. The colors of some stars can be seen with the unaided eye. However, astronomers use special filters on telescopes to determine the colors of most stars.

The most common type of star in the universe is the red dwarf, which is much smaller than the sun and may live trillions of years. Even though they are common, you can see only a few of them from Earth. This is because they are so small and they release very little light.

Blue giant stars are much larger than the sun. They are very hot, very bright, and burn up their fuel relatively quickly. They can last several tens of thousands of years. Many of the stars that are visible at night are blue giants, even though they are rare compared to the other types of stars. They are easily seen, even from far away, because they are so bright.

The sun is a yellow star. How does a yellow star compare with red dwarfs and blue giants? Think about size, temperature, and how long each lives.

Galaxies

Some of the white points in the sky are not really stars at all. They are entire galaxies. Only when you look at them through a telescope can you see that something that looks like one point is actually made up of many stars.

There are probably more than 100 billion (100,000,000,000) galaxies in the universe. Some contain only 10 million stars, while others have as many as one trillion (a thousand billion) stars. All of these galaxies are so far away from Earth that without a telescope, you can only see a dim, fuzzy spot in the sky.

The sun belongs to a galaxy called the Milky Way. The Milky Way is estimated to contain 200–400 billion stars. The supernova Brahe observed was once one of these stars, which is why he could see it so clearly. If it had belonged to another galaxy, it would have been too far away to be seen without a telescope.

The universe is huge!

One of the difficult things to understand about the universe is its scale: the large numbers, sizes, and distances involved. The universe is huge compared to everything you know from daily life. For example, the closest star to Earth, other than the sun, is about 38,624,256,000,000km away. It would take the fastest spacecraft ever developed about 10,000 years to get there! Most stars are millions and billions of times farther away than that.

When you start thinking about such immense distances, a kilometer or a mile is not a practical unit to use because the numbers get too big. No one wants to write or talk about numbers that have more than 10 digits in them. To measure distances in space, scientists use a unit called a light-year.

Light travels at a speed of 299,338km/s. That means that in one second, light travels 299,338km. A light-year is the distance that light travels in a year. In one light-year, light travels 9,454,254,955,500km. Even though people usually use the word year to measure time, when talking about the universe, scientists use the term light-year to measure distance. It would be less confusing if the same word wasn't used to describe time and distance, but it's what we're stuck with!

What does a light-year measure?

The universe is very old

When you gaze at objects in the night sky, you are looking back in time. This doesn't seem to make sense at all! It can take light from a star so many years to reach Earth that when you look at the star, you are seeing light that may have been produced billions of years ago. The farther the star is from you, the longer its light takes to reach you, meaning that you are looking farther back in time.

For example, light from the sun takes 8.5 min to reach Earth. Stop and think about that for a moment: When you look at the sun, you are actually seeing the sun as it looked 8.5 min ago!

The next closest star is about four light-years away from Earth. Light from this star takes four years to reach Earth. When you look at it, you see it as it looked four years ago. It takes billions of years for light from the farthest stars to reach Earth, so when you look at them you are looking billions of years into the past.

Astronomers estimate that the universe first appeared about 13.7 billion years ago. They estimate this age from data about the distances between stars and galaxies and the speed at which those objects move through space. For comparison, data from the rock and fossil record suggest that humans first appeared only about 200,000 years ago. These kinds of numbers are difficult for us to imagine, which can make studying the universe very challenging!

The numbers themselves aren't as important as recognizing their scale. Understanding how large objects in the universe are and how much distance is between them helps you to learn how big and how old the universe really is. Scientists don't know everything about the universe. But studying the objects that make up the universe helps us understand the natural laws that control sunrises, sunsets, eclipses, weather, and climate on Earth.

The universe is constantly changing

If you could go back in time, you would see that the galaxies were once closer to each other than they are now. About 13.7 billion years ago, all of the matter that existed was at the same spot, in a very tiny space. What happened then? Scientists think that the entire universe began in a “Big Bang” that sent everything moving outward in all directions. People often think that the “Big Bang” was an explosion, like popcorn popping. But it was more of an expansion, like someone blowing up a balloon. Scientists estimate that the observable universe is a sphere with a diameter of about 92 billion light-years.

Not only is the universe still expanding, but stars are born and die all the time. In fact, when you look at the sky, some of the stars you see do not exist anymore. By the time their light has reached Earth, these stars may have exploded or cooled down and died.

What we do not know about the universe

You have learned things about the universe that were not known when Brahe was studying the sky. There is still a lot to learn about planets, moons, asteroids, and other objects. There are many puzzles to be solved, and many challenges for future scientists.

> In the space below, write a question or two (or more!) that you have about the universe and anything in it. In the rest of the unit, you can try to learn the answers. Maybe you want to learn more about astronomy as a career, or as a hobby.

Activity 2.2: Motions of the Solar System

What Will We Do?

In this activity, we will model the orbit of planets around the sun. We will also demonstrate how planets would move without the gravitational effects of the sun. This will help us draw conclusions about the effect of the sun's gravitational pull on the shape of the orbits of planets.

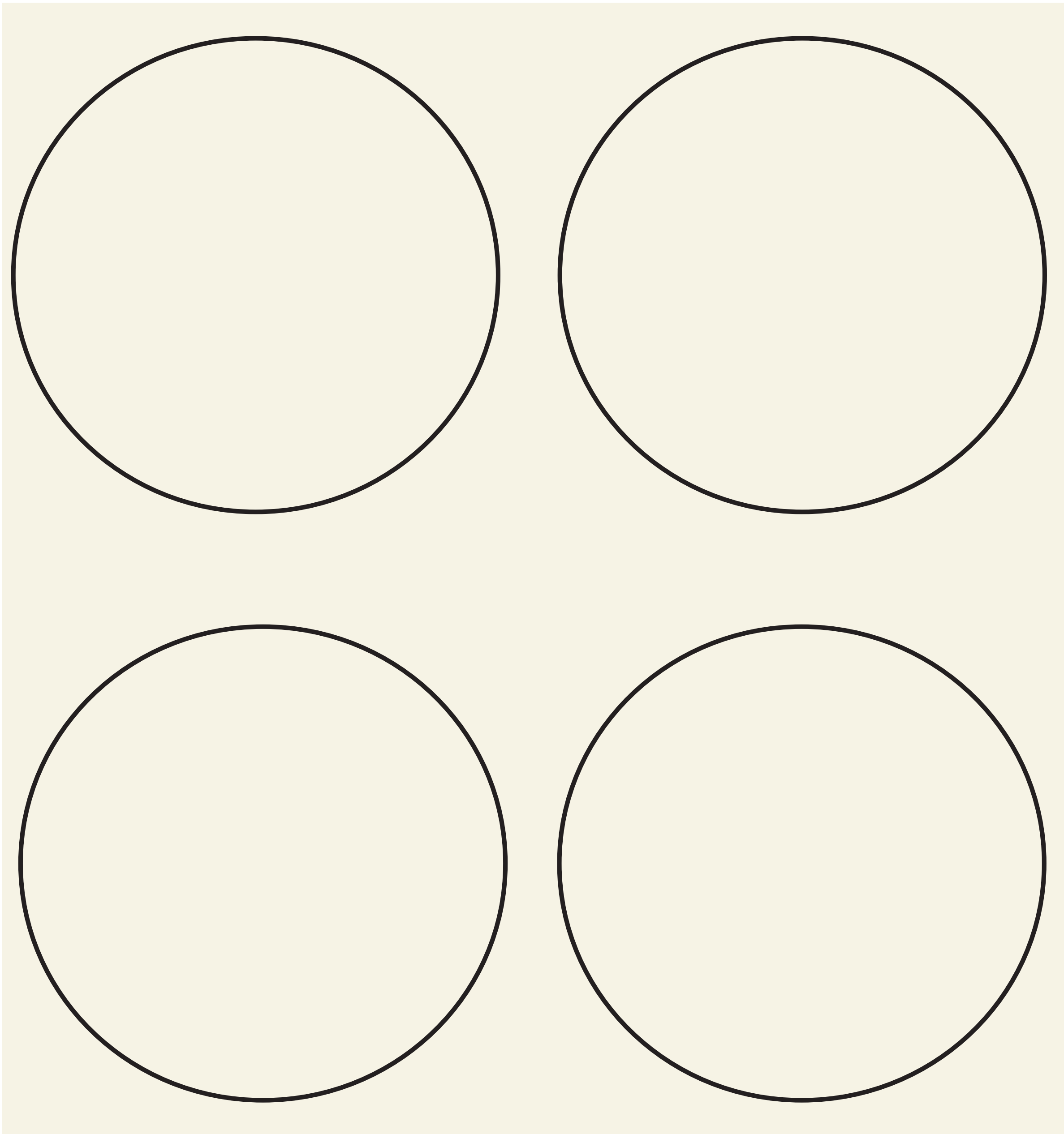
Procedure

- ☐ a. Your teacher will provide you with a hoop, a marble, and a large square of butcher paper.
- ☐ b. Place the hoop in the center of the paper, and use your pencil to carefully trace the outline of the hoop on the paper.
- ☐ c. Place the marble against the inside edge of the hoop.
- ☐ d. Hold the hoop firmly against the paper and begin gently moving the hoop in a circular motion. Try to create a rhythmic motion so that the marble rolls smoothly around the edge of the hoop at a fairly constant speed and in a counterclockwise direction.
- ☐ e. Once the marble is "orbiting" smoothly, lift one edge of the hoop off of the paper by about 3cm. Record what happens to the marble by using your pencil to trace the marble's path on the paper.
- ☐ f. If there is time, repeat step e. Each time, lift a different spot on the hoop, and record your observations.

Record your data.Then compare answers with your partner. If time allows, join with another group to share your results.

Data

Plot your results on the images provided below.



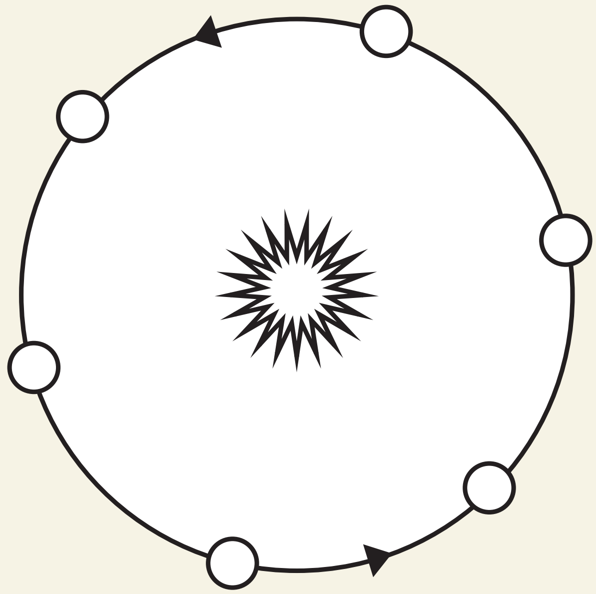
Making Sense

1. What did the hoop represent?

2. What happened to the path of the marble when you lifted the hoop?

3. If the marble represents an orbiting planet, where would the sun be located in the model?

4. Look at the image (below) that shows the orbit of a single planet around the sun. Label the diagram, using a colored pencil to draw arrows that represent the direction of the gravitational force the sun applies to the planet at each location. Use a different colored pencil to draw arrows that represent the direction the planet would move at each location if the sun's gravity were not pulling on the planet.



5. Write an explanation of how gravity affects the orbits of planets in the solar system.

Activity 2.3: Apparent Motions of Stars

What Will We Do?

In this activity, we will use sky charts to investigate what stars and constellations tell us about how Earth moves in space.

Procedure

- ☐ a. Examine the series of maps of the sky carefully. For each map, identify the time, count the constellations you can see, and record that number in the Data section.
- ☐ b. Focus on the constellation Orion in relation to the directional markers on the bottom of the map.
- ☐ c. Use the blank sky chart below to record the location and position of the constellation Orion in the sky.

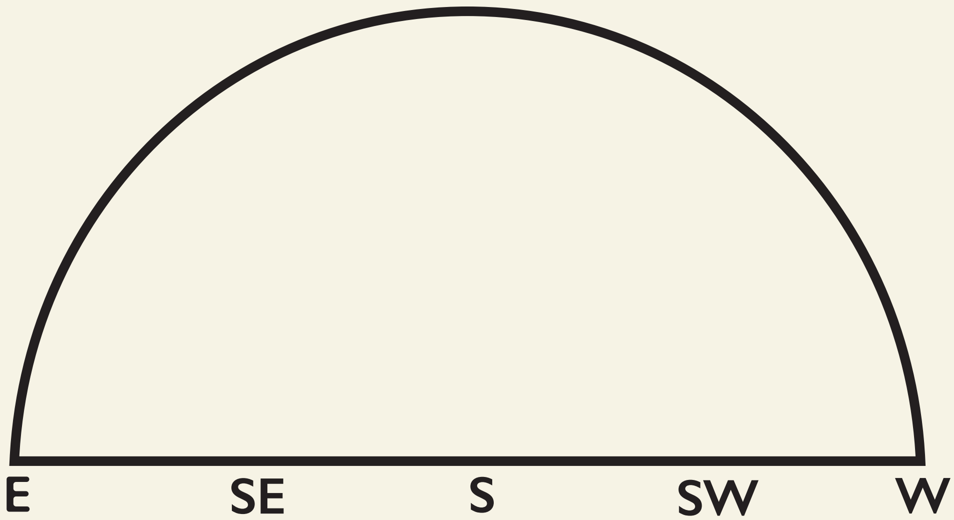
Record your data below. Then compare answers with your partner. If time allows, join with another group to share your results.

Data

Part 1

How many different constellations did you see in the sky over the course of one night?

Plot the path of the constellation Orion over the course of the night by drawing the constellation or applying the stickers of the constellation in the correct places on the map and labeling the time for each position.



Making Sense

Part 1

1. How did the constellation Orion's position change between 7 p.m. and 5 a.m.?

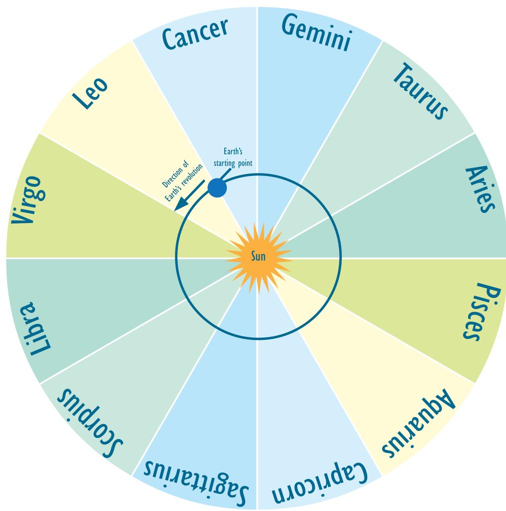
2. What causes the pattern of movement you observed in the stars during a single night?

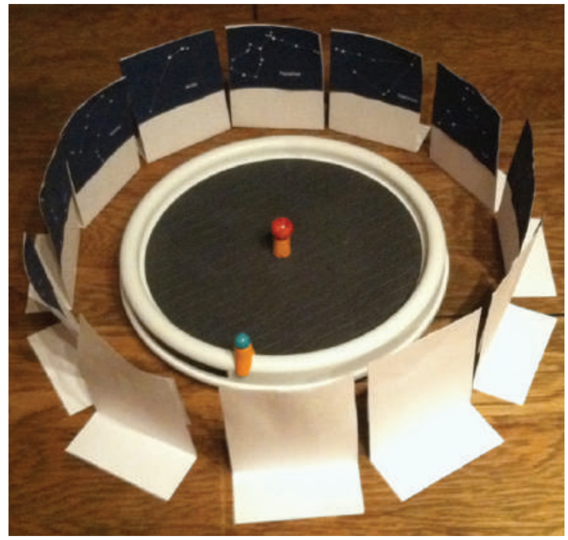
Procedure

Part 2

☐ a. Your teacher will provide you with a rotating tray, two marbles, a small lump of clay, and twelve constellation cards. Use these materials and the diagram and photo below to set up your model.

1. Use modeling clay to create a stand for the sun in the center of the rotating tray. Place the marble that represents the sun securely on this stand.
2. Use modeling clay to create a stand for the Earth on the edge of the rotating tray. Place the marble that represents Earth securely on this stand.
3. Place the constellation cards around the outside of the rotating tray in the order described in the diagram.
4. Align the marbles for Earth and the sun as shown in the diagram. This starting point represents the position of Earth in its orbit in the month of January.





- ☐ b. Once you have set up your model and placed Earth in the starting position shown in the diagram, view Earth and the sun from between the cards and identify the constellations to the left and right of the sun and Earth. You will view the model from two opposite directions. You will view the sun and the constellations behind it from the Earth's position. You will view the constellations in Earth's night sky from the opposite side of the model, from the sun looking toward Earth.
- ☐ c. Use the table provided to record your observations of the constellations that the sun would appear to be in and the constellations that would be visible from the night side of Earth.
- ☐ d. After you record your observations, rotate the tray counterclockwise to align Earth with the gap between the next pair of cards. You will have to move around the model to view the constellations from both directions. Repeat this step until you return to your starting point.

Record your data. Then compare answers with your partner. If time allows, join with another group to share your results.

Data

Part 2

Fill in the table below to show which constellations are visible during each month.

Activity	Zodiac constellation(s) through which the sun appears to pass	Zodiac constellation(s) visible in the night sky
January		
February		
March		
April		
May		
June		
July		
August		
September		
October		
November		
December		

Making Sense

Part 2

1. How many different zodiac constellations does the sun appear to move through over the course of one year?

2. How do you know that the sun only appears to move through those constellations—that it doesn't actually move through them? Explain your ideas.

3. How does the motion of the stars over a single night differ from the motion of the stars throughout the year?

4. What causes the pattern of movement you observed in the stars over the course of an entire year?