HOW WILL IT MOVE?

Force and Motion

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Investigating and Questioning Our
World through Science
and Technology
(IQWST)

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About the Publisher

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ART

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Lesson 6

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Lesson 7

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Lesson 1

Anchoring Activity and Driving Question Board

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

1. 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.

2. 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.

3. 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?"

Reading 1.2 – Newton's Cradle

Getting Ready

Have you ever played pool? The game begins with a breaking shot in which a player scatters several balls that are grouped together by shooting one ball into them. What do you think would happen if the balls were lined up, touching one behind the other instead? This reading may help you answer this question and to think about forces.

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

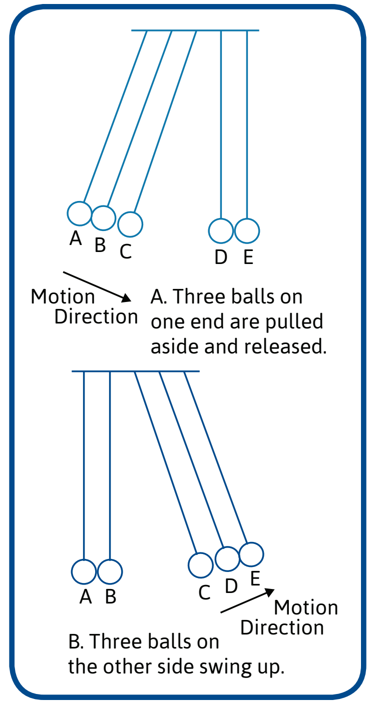
What would you think of if you saw an apple fall from an apple tree? You probably would not think much about it. Isaac Newton, whom many people consider the greatest scientist ever, thought about it a lot. Newton was a physicist and a mathematician. He lived in England more than 300 years ago (1642–1727). 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?



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.

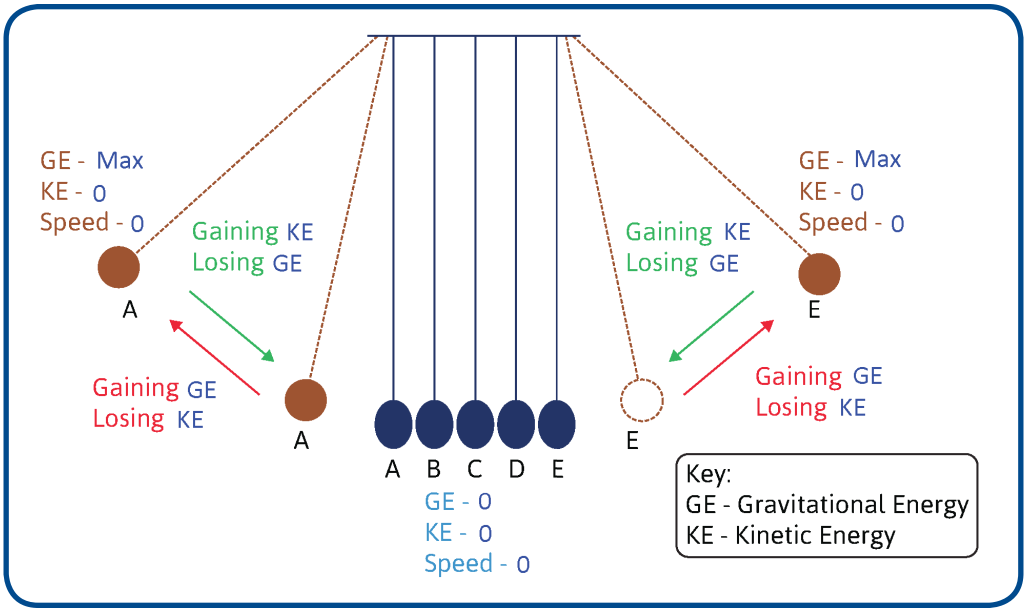
Energy Transformations in Newton's Cradle

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.

LESSON 2

Which Forces Act on an Object?

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

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

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

2. Which components of this system interact with each other?

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

4. How many forces does each person apply?

5. How many forces act on each person?

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

7. Does your chair push up on you?

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

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

Conclusion

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.

1. 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?

2. Do the magnets have to be in contact to apply a force to each other or can they act at a distance?

3. Do the magnets apply pull forces or push forces to each other, or can they apply both? What is your evidence?

4. Do these forces become stronger or weaker as the magnets get nearer to each other?

Conclusion

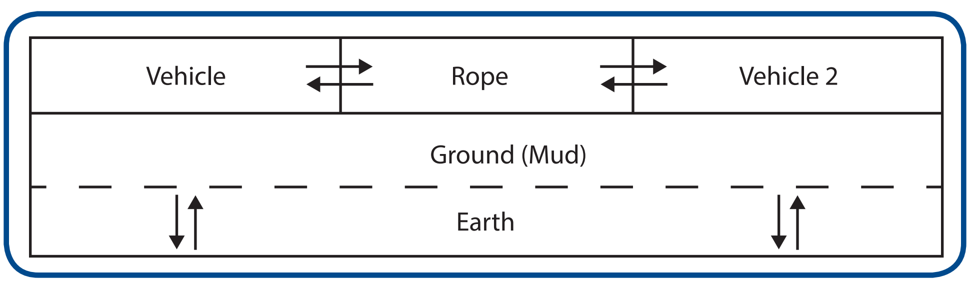
1. What type of force keeps atoms together in a molecule?

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.



Reading 2.3 – 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.

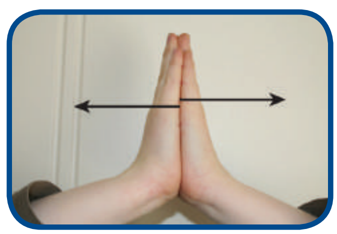
When you succeed, you might want to take a picture of yourself with these physics stunts and show them to your friends. If you print the photo, you can attach it here:

1. 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 pair 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.

2. 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.



3. 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.

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

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.

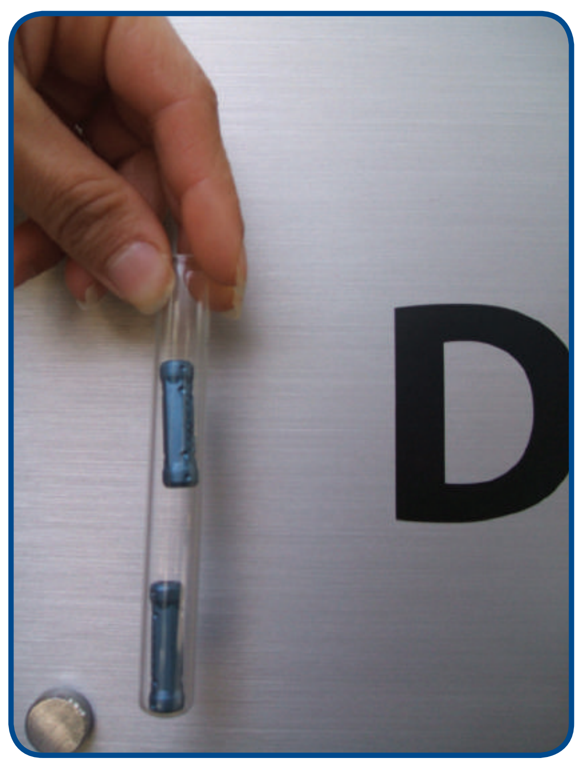
5. Which of the marked apples in the picture interact with Earth by at a distance forces? Explain your choice.

   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.

6. 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.

7. 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?

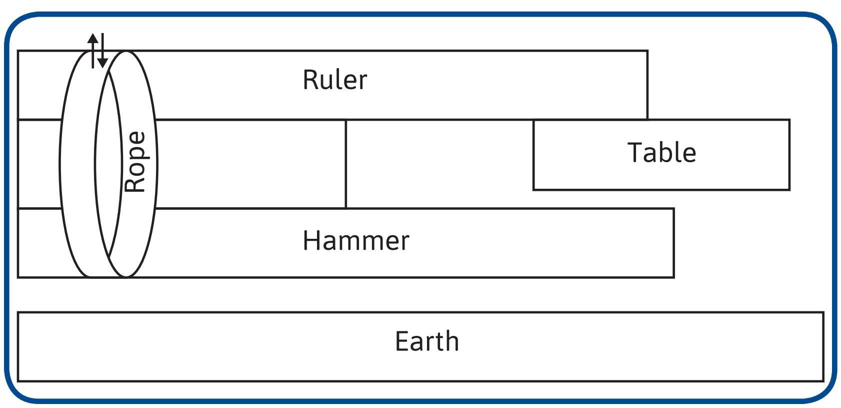
Modeling the Interactions in the Hammer and Ruler System

8. 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	+	+	+	+	

9. 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

1. Construct a model of each device that represents its components.
2. Use arrows to represent in each model the forces that affect its motion.

Data Collection/Observation

Station #1 – Flying Balloon

- The components of the system are

- The forces acting on the system's components are

Station #2 – Floating Magnets

- The components of the system are

- The forces acting on the system's components are

Station #3 – Air-Powered Car

- The components of the system are

- The forces acting on the system's components are

Station #4 – Magnetic Cannon

- The components of the system are

- The forces acting on the system's components are

Lesson 3

Why Does an Object Start Moving?

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

1. 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.

2. 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.

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

4. Which of these forces act horizontally and which act vertically?

5. 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

1. 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:

   a. The ball will move away from you and toward your partner.

   b. The ball will move away from your partner and toward you.

   c. The ball will not move.

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

3. 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?

4. Which forces do you think influence the ball's horizontal motion? Why do the others not affect its horizontal motion?

5. 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.

6. Suppose we pushed the ball with both hands but pushed harder with Hand 1 than with Hand 2. The ball responds in a certain manner. Can we get the ball to respond in the same manner while pushing it with only one hand? If yes, with which hand should we push the ball and how hard should we push it? How hard should you or your partner push?

7. How hard must each of you push to keep the ball motionless?

8. Draw a free-body diagram of a ball held in your hand before it is dropped.

Conclusions

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:

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

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

3. Draw a free-body diagram of the bag.

4. 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:

1. In the Floating Magnets, explain why the upper magnet floats.

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

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

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

5. What are the two forces that are applied to the upper magnet?

6. Which of these forces pull or push upward, and which pull or push downward? Explain.

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

8. When will the magnet start moving up or down? Explain.

9. Does the lower magnet float as well? Explain.

10. Which horizontal forces act on the last ball?

11. How do you know what is the direction of these forces?

12. What must be the relationship between these forces for the last ball to begin moving outward?

13. Why do you think the car and the fan can be thought of as a single object?

14. Which horizontal force acts on the car-fan?

15. How can the air apply a force to the car-fan?

16. In which direction does the air push the car-fan?

17. Why can the balloon and the straw be thought of as a single object?

18. Which horizontal force acts on the balloon-straw?

19. How can the air apply a force to the balloon-straw?

20. In which direction does the air push the balloon-straw? Explain.

Conclusions

1. Under what conditions do forces counteract each other?

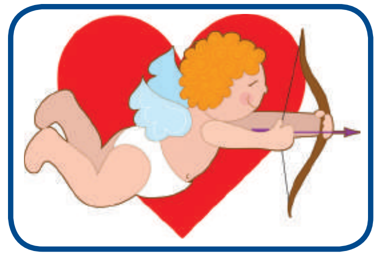
2. Under what conditions do forces reinforce each other?

3. Under what conditions do forces cancel each other?

Reading 3.3 – 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?

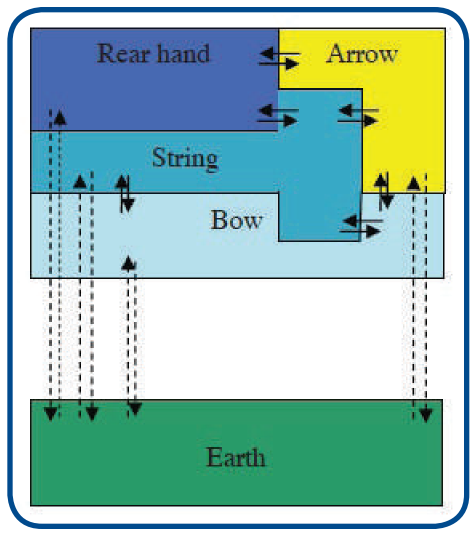
In this reading, you will learn about flying arrows, arm wrestling, and cola that sprays out of its bottle. You will see how forces can explain what happens in each case.

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.

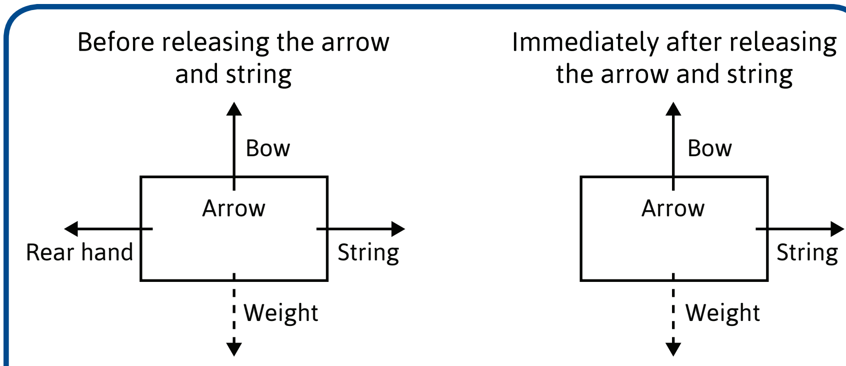
Forces in a Bow and Arrow

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.



Free-body diagrams of the arrow

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

1. 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?

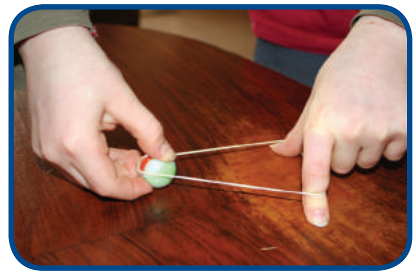
2. Which forces act on the arrow before it is released? For each force, specify three things: (1) its direction, (2) whether it is a contact force or a force that acts at a distance, and (3) whether it is a pull or a push force.

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

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

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

Starting Motion

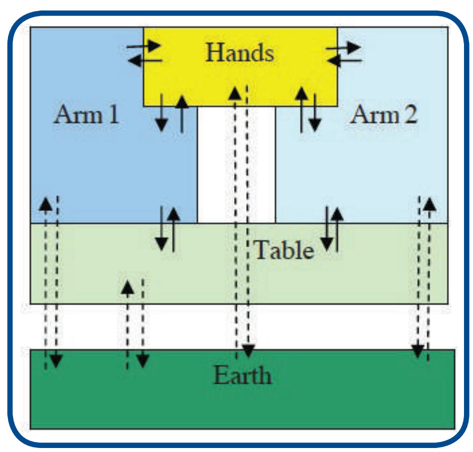


In class you learned that a marble shot by a stretched rubber band began moving because a force was applied to it, just like with the bow and arrow. In both systems, before the marble or arrow is released, there are four forces—two horizontal forces (one pushes forward and the other pulls back) and two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

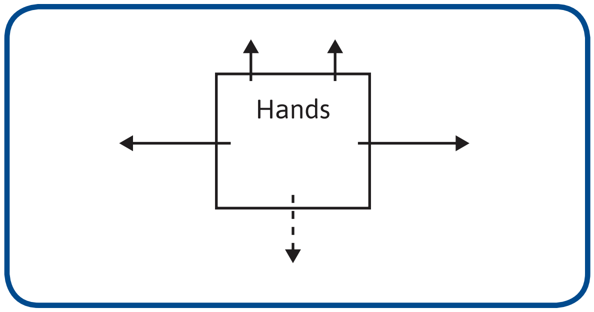
Arm wrestling is another way to think about forces and about starting motion. Imagine two students preparing to arm wrestle. One student is wiry and slim and the other is big and muscular. Who do you think will win? In arm wrestling, the muscles of each opponent's arm apply a force to their own hand,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

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

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



7. 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 fight? Explain your ideas.

8. After a while, the thin and wiry 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.

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

10. 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?

11. 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.

12. Draw a free-body diagram showing the forces that act on the bottle of 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.

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

14. 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?

15. 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.

16. 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.

Lesson 4

How Strong Is That Force?

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:

1. Does a spring get stretched by the same amount each time the same mass is hung from it?
2. Does a spring return to its original shape each time after the mass hanging from it is removed?
3. What is the relation between the amount a spring gets stretched and the size of the mass hanging from it?
4. 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" created by putting metal objects called "washers" on the spring. First use 1, then 2, then 4 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.

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

2. Draw a model showing the setup and the forces acting between them.

3. Record your results here.

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

4. 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 = 5N.

1. 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

2. What is the difference between mass and weight?

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

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

5. 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)

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

Conclusion

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.

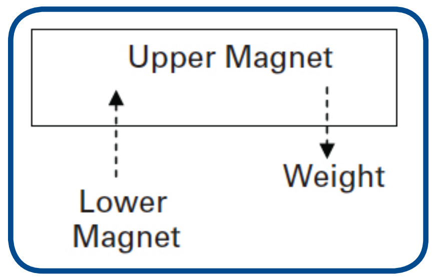
Procedure

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 = ______________________________

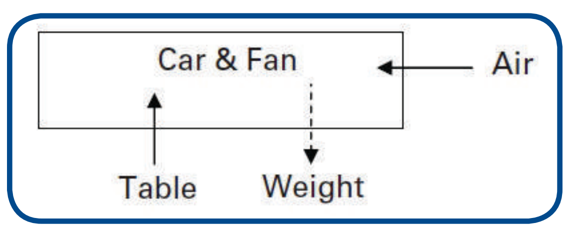


Air-Powered Car

Weight of Car and Fan = ______________________________

Force of Table on Car and Fan = ______________________________

Force of Air on Car and Fan = ______________________________

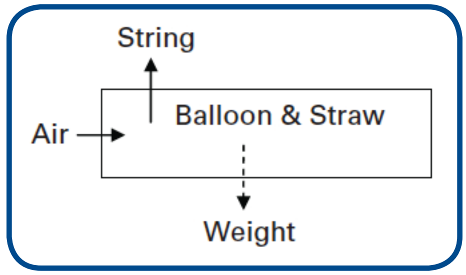


Flying Balloon

Weight of Balloon and Straw = ______________________________

Force of String on Balloon and Straw = ______________________________

Force of Air on Balloon and Straw = ______________________________



Reading 4.3 – 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?

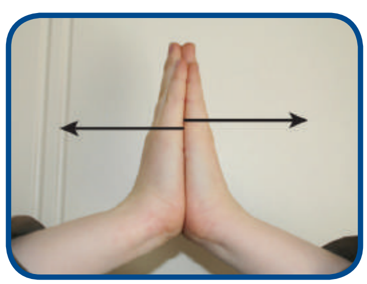
1. Write your ideas:

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.

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

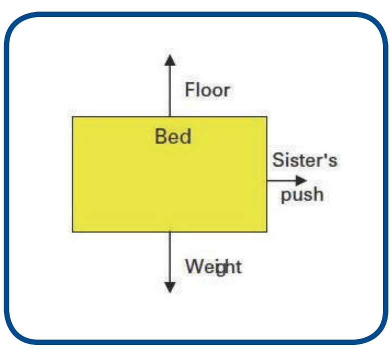
What Makes it Difficult to Move Furniture?

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.

3. 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?

4. 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.

5. 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.

6. 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.

7. 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?

8. 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.

9. 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.

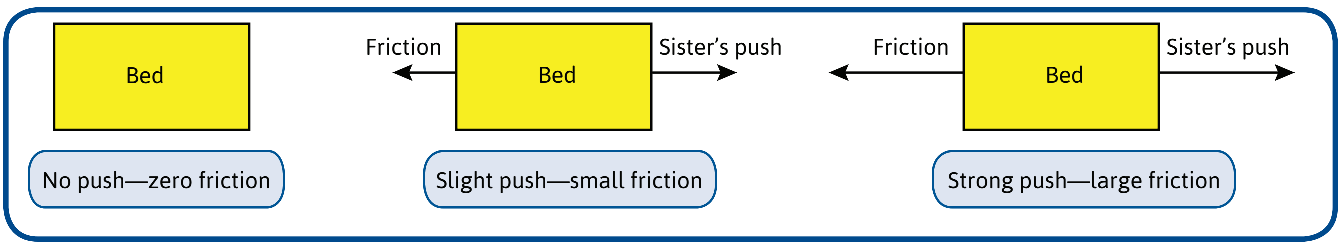
10. Would the free-body diagram look any different if instead of attaching wheels to the bed, you waxed the floor? Explain your ideas.

11. 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.

12. 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 more 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.



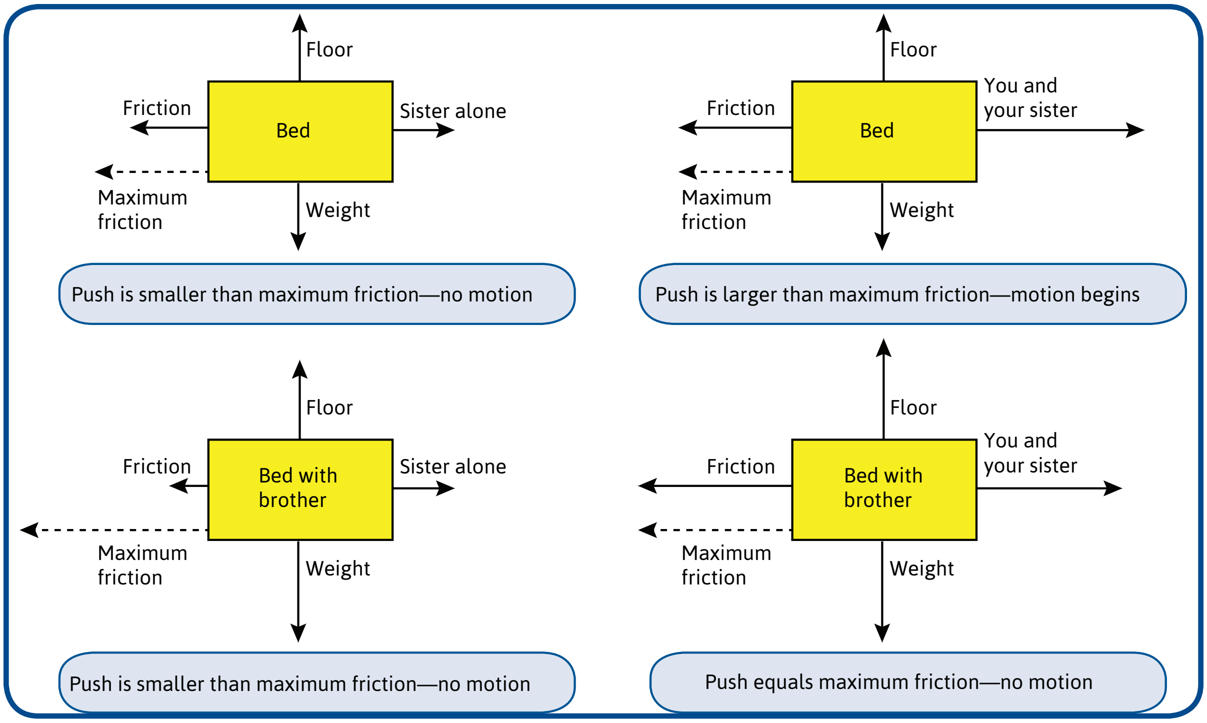
Once you join your sister, the push force becomes so great that the friction can no longer increase enough to balance it. There is a limit to how big friction can get. When friction reaches its limit, it cannot increase anymore. If the push force is greater than the maximum strength the friction can 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, ask your teacher for the next 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.

Reading 4.4 – Who Will Win a Tug-of-War?

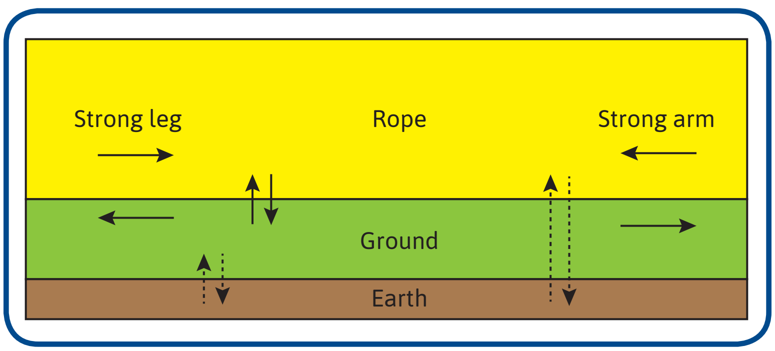
Getting Ready

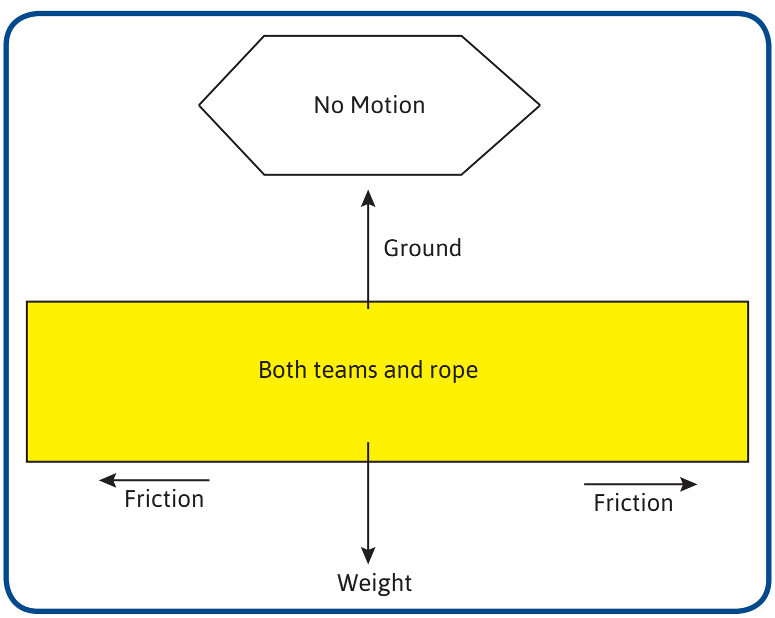
Remember the strong-leg and strong-arm tug-of-war teams from the previous reading? In that reading, you were asked to explain why the strong-arm team won. You may have answered that the strong-arm team won because they pulled the rope harder than the strong-leg team. This is true, but it is not the complete 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.



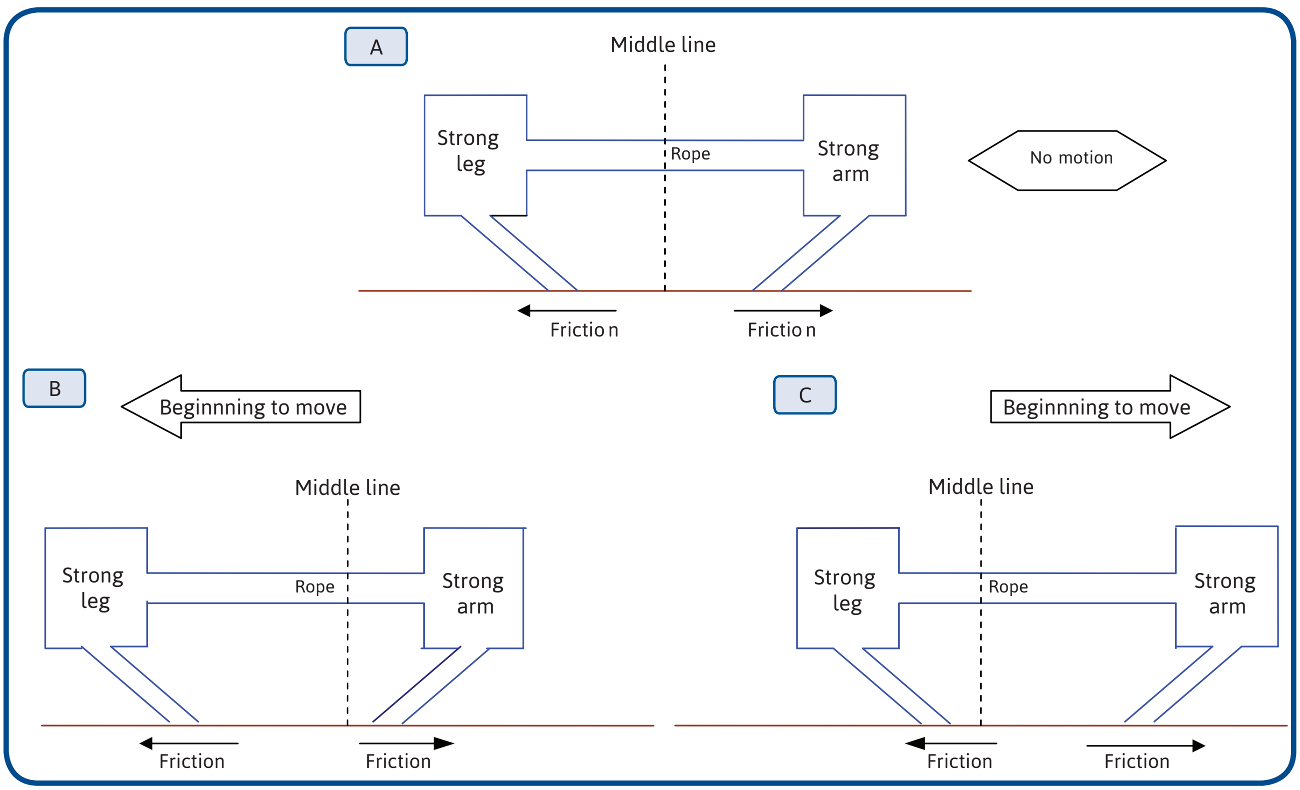


1. According to the free-body diagram, which forces act on both teams and rope before motion begins and in which directions?

2. 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.



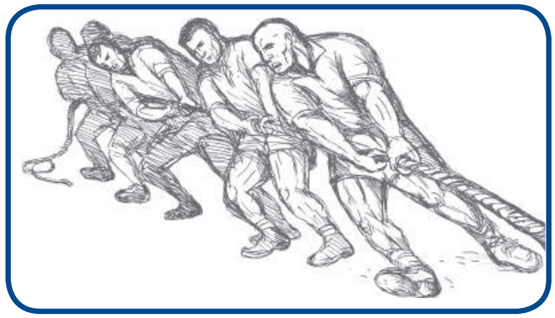
3. Look at the free-body diagrams. Which forces act horizontally on both teams and rope? What forces may affect the dragging of one team by the other?

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.

4. 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.

5. 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.

6. Do you think heavier players have an advantage in a tug-of-war? Explain. To fully answer this question, revisit Reading 4.1 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.

7. 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.

Lesson 5

Why Does an Object Stop Moving?

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.

1. 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.

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

3. 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.

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

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

6. 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.

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

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

Conclusion

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

Homework 5.1 – Hard and Soft Landings

Have you ever noticed that when people jump up and down, such as when playing basketball or volleyball or jumping to get something off a high shelf, they always bend their knees a bit? Why is this?

Find a low stool or chair and jump off of it. You need not jump up or away from the stool; just jump lightly off of it.

1. Do you instinctively bend your knees a bit when you land? Why do you think your body does this?

Jump off the stool twice again. Once, try and land without bending your knees. (You may be surprised how hard it is to overcome your instinct to bend your knees.) The second time, bend your knees more than usual.

2. In which case did you feel a harder impact with the ground?

3. Draw a free-body diagram of your body hitting the ground.

4. Which vertical forces act on your body when it hits the ground?

5. When your body hits the ground, does an overall upward force or downward force act on it? Explain.

6. In which case do you think the overall vertical force your body felt when it hit the ground was greater—when you bent your knees or when you kept them straight? Explain.

7. A large force can make your bones break, damage the discs in your spine, or other unpleasant things. Why do you think you instinctively bend your knees when landing after jumping?

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.

1. What happens to the when the last ball shoots out?

2. 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.

3. What makes the move backward?

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

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

Reading 5.2 – 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. 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 experimented with books stopping their motion 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 the air cushion died. 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 turned off?

If the air cushion dies, 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.

Lesson 6

How Can We Describe How an Object Moves?

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

1. 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.

2. 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.

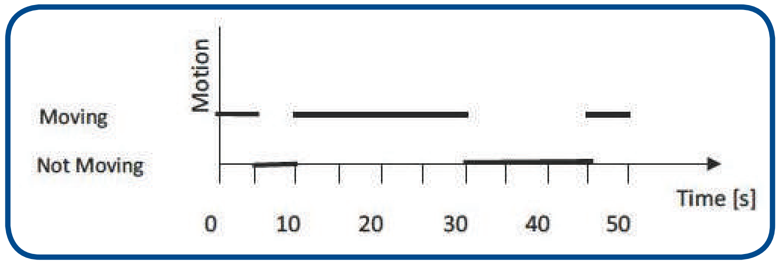
Here are some things you should think about as you draw your graph:

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?

Homework 6.1 – Rat Race

Some friends got together to race their pet rats on a racetrack. They built a racetrack that was made up of sections. At the end of each section, they put a piece of cheese, which the rat had to eat before continuing to the next section.

A motion graph for one of the rats is shown. The times the rat is not moving are the intervals when the rat was eating a piece of cheese. The bigger the piece of cheese, the longer it took the rat to finish it. The longer the section between the pieces of cheese, the longer it took the rat to run it.



1. How long did it take the rat to finish the race?

2. How many pieces of cheese were there? Which piece of cheese was bigger? Explain.

3. Did the rat spend more time running or eating? Explain.

4. Redraw the graph to show how it would look if all the running sections were cut in half and the amount of cheese the rats had to eat at each station was doubled.

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.

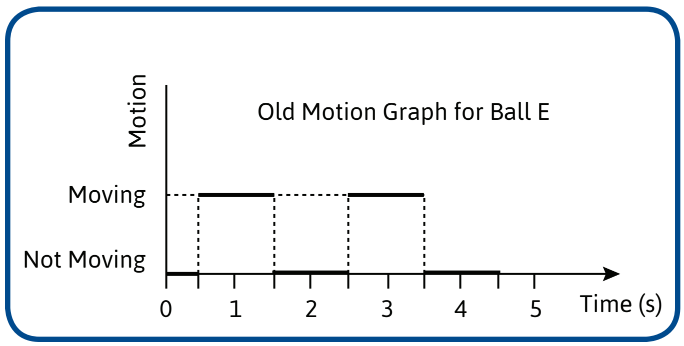
Procedure

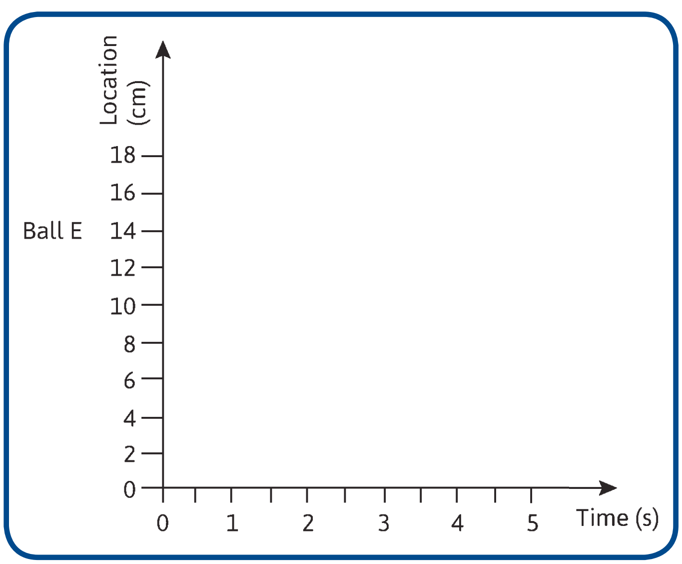
Your teacher just showed you how to make a motion graph for Ball A (the ball that the teacher lifted and then dropped) that shows how the ball moves, not just when it moves.

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:

1. The graph you made in Activity 6.1 that shows when Ball E moves

2. A pair of axes for the new graph you will draw

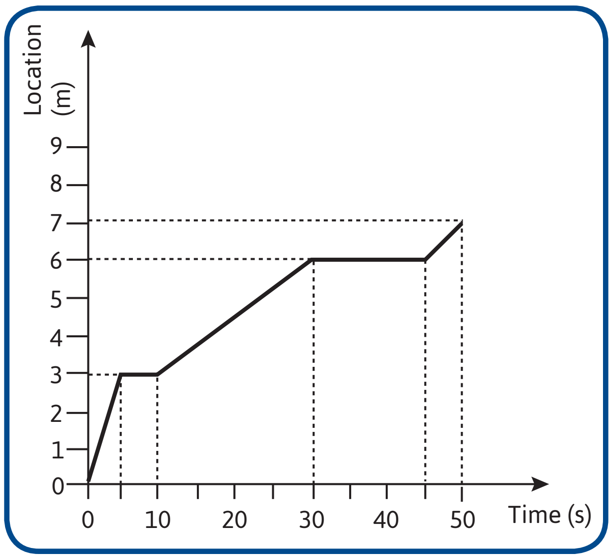




Homework 6.2 – Rat Race Part 2

Remember the rat race from Homework 6.1? The friends got together and repeated the race. They got the same results, but because they had studied physical science since the last race, they were able to draw more sophisticated motion graphs of the results.

The following graph shows the results of a single rat, the same one we looked at last time.



1. What was the length of each section the rat ran? What was the length of the entire racetrack?

2. During which section did the rat run the fastest? How do you know?

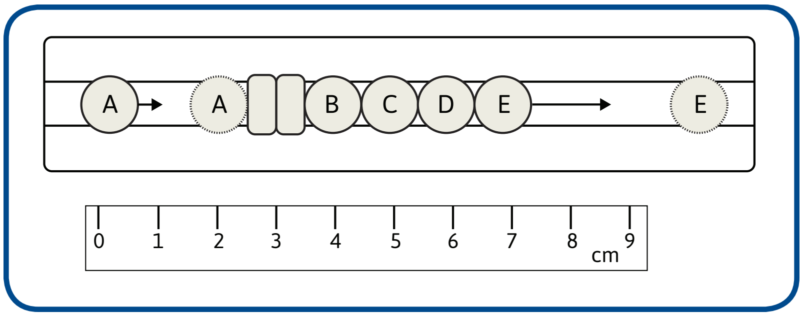
ACTIVITY 6.3 – MOTION GRAPHS FOR THE MAGNETIC CANNON

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.

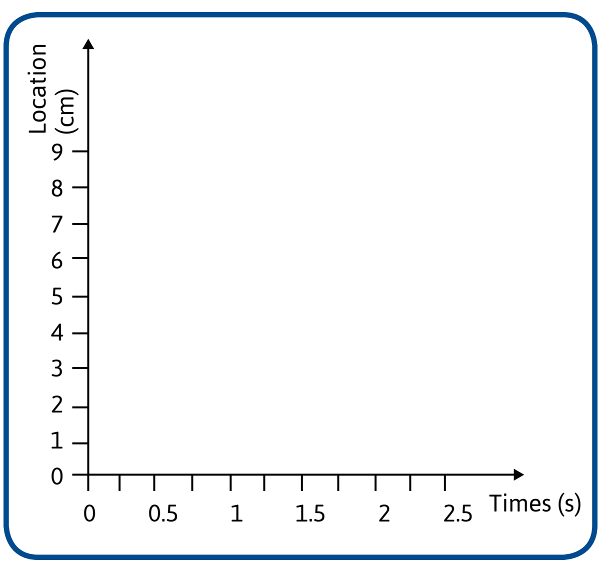
Procedure

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?



Conclusion

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 inclination?

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

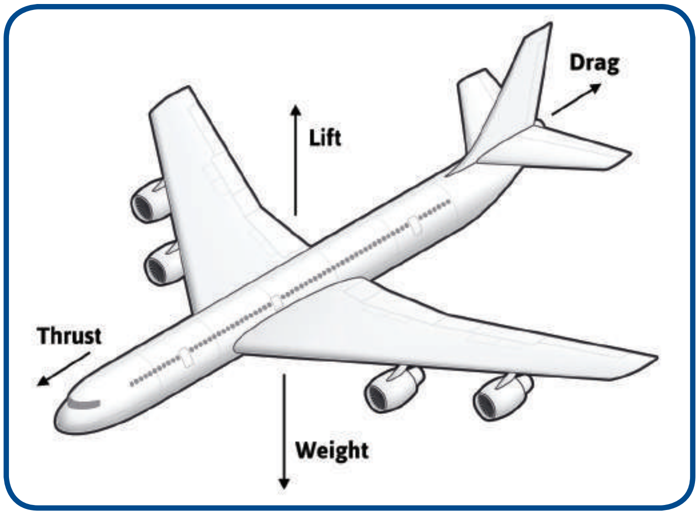
Why Do Things Change Their Speed or Direction?

What Will We Do?

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

Procedure

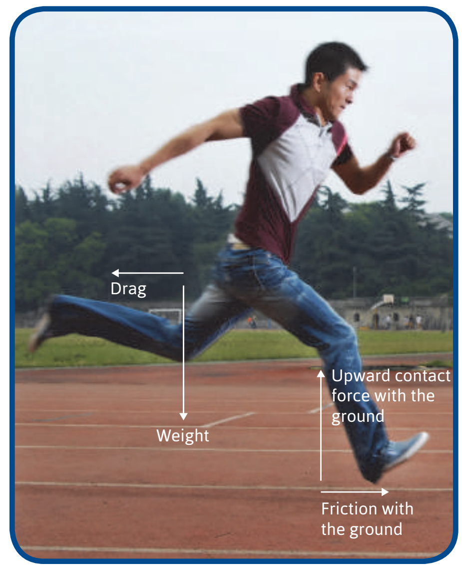
1. Every airplane has at least four different forces acting on it: the thrust of the engines that push forward, the drag (friction) of the air that pushes backward, its weight that pulls it down, and the lift on the wings that push upward. Assume that the plane in the drawing is slowing down while flying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



2. 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.

3. A runner is speeding 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.

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

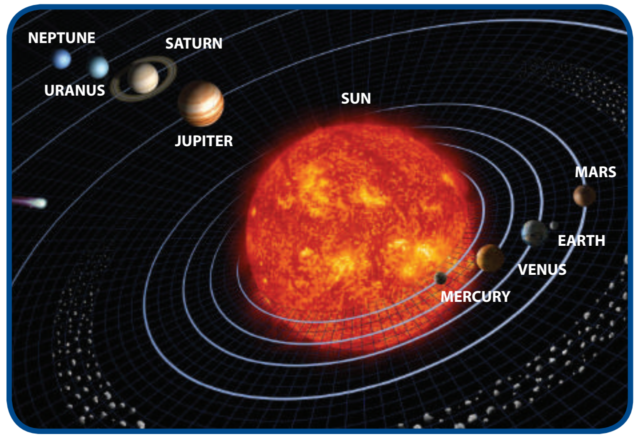
2. Does the direction in which the ball was tapped (perpendicularly to its original motion, slanted backward or slanted forward) have any effect on the direction in which the ball changes direction?

3. 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.

4. 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.

Reading 7.2 – Planetary Motion

Getting Ready



You have probably seen many representations of our solar system. Maybe you've even made one. People often use mobiles, drawings, or 3-D objects to represent the sun and planets in our solar system. Most, like the one pictured here, allow you to see the position of the bodies in relation to each other. You can see which planet is furthest from the sun and which is closest to it. This diagram also shows the shape of each planet's path (orbit) around the sun.

Most of these representations are not actually "models" because, as you have learned, models allow you to predict or explain how and why a phenomenon occurs. Models aren't just to "show" something. But like models, this diagram has limitations. For example, the sun looks about 50 times larger than Earth, but it is actually more than 300,000 times larger! This diagram also does not enable you to explain how forces work in the solar system. As you read, you'll learn more about how forces explain orbits.

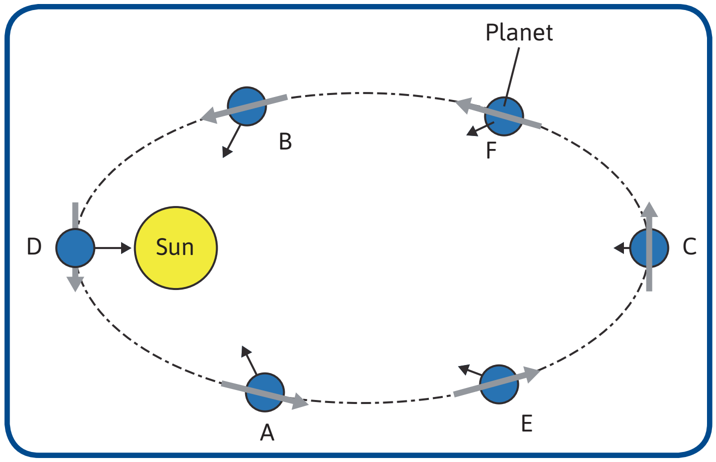
What Makes the Planets Move?

The planets move around the sun. What makes the planets move around the sun instead of toward it or away from it? You have learned that forces can make things go faster or slower, and forces can also make moving things change their direction. The force that makes the planets move around the sun is gravity. Every two objects apply a gravitational force on each other. The more mass objects have, the greater the gravitational force they apply to each other. Gravity is actually a very weak force and only very heavy objects can apply a gravitational force that is large enough to be felt. For example, when you put your school bag on the floor next to your sneakers, they stay apart even though they apply a gravitational force to pull on each other. This force is much too weak to overcome the friction between each object and the floor. In fact, the gravitational force is so small that the most sensitive force probe would not be able to measure this force. However, when objects are really heavy, such as planets or the sun, the gravitational force they apply is large enough to influence the motion of other objects. Their gravitational force can make objects slow down, speed up, or change direction. Remember Newton's apple falling from the tree? Because Earth is very large, the gravitational force it applies to a small apple is large enough to pull the apple down from the tree and make it fall.

The sun's gravity pulls on the planets in much the same way that Earth pulls on an apple. If the planets were motionless, they would fall directly toward the sun, just as the apple falls directly toward Earth. However, the planets are not motionless. Each planet is moving in a direction that is not toward the sun. This means that the sun does not pull them in or against the direction of their motion, but rather it pulls them sideways, so they change their direction of motion. The pattern their motion makes is called an *ellipse*, which is an oval shape.

Representing a Planet's Orbit

Look at the drawing that shows the motion of a single planet around the sun. The wide arrows represent the direction of the planet's motion at different locations. The thin arrows represent the direction of the gravitational force the sun applies to the planet at different locations.



A planet's orbit around the sun

Newton's first law of motion states that if an object is not subjected to imbalanced forces, it will maintain its state of motion. If the object were at rest, it would remain at rest. If it were in motion, it would continue to move in the same direction and at the same speed. If there had been no gravitational force, the planet would not have changed its direction to orbit the sun. It would have continued moving in a straight line at a constant speed from wherever it was located.

However, there is a gravitational force, and this force makes the planet change its direction. Depending on where the planet is located, it might also speed up or slow down based on the exact direction of the gravitational force. This is because the gravitational force is almost never exactly sideways; it is usually directed to the side and a bit forward or backward. The force the sun applies on the planets also makes them change their speed.

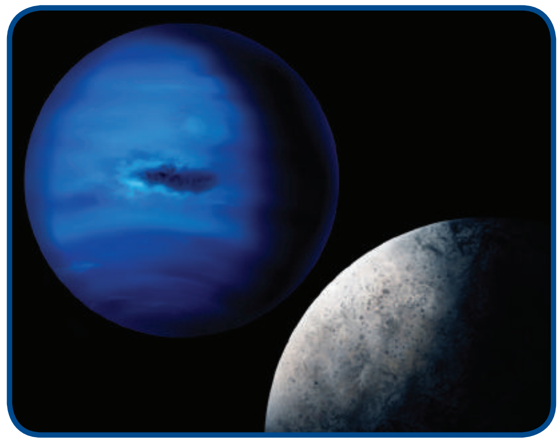
Look at the drawing again. When the planet is in position A, the sun pulls the planet backward and sideways. That makes the planet curve and slow down. When the planet is in position B, the sun pulls the planet forward and sideways, making it curve and speed up. As the planet travels, the same thing occurs—it is constantly speeding up and slowing down, curving slightly to its side, making an ellipse around the sun.

In which of the positions in the drawing (A, B, C, D, E, F) do you think the planet moves fastest and in which do you think it moves slowest? Explain your ideas.

Just as the sun's gravity pulls on the planets, the planet's gravity also pulls on the sun. This is Newton's third law of motion. The planet's gravitational forces affect the sun's motion. Since the sun is much heavier than the planets, it is much harder to move. The gravity that the planets apply barely affects the sun. Do the planets apply a gravitational force to each other?

The Discovery of Neptune: Planets Affecting Each Other

Neptune was discovered in 1846, but it was not discovered with a telescope, as other planets were. Instead, astronomers predicted that it existed using a precise mathematical model of the solar system. This model took into consideration not only the gravitational pull of the sun but also the gravitational pull of the planets on each other. According to this model, the astronomers calculated how each planet's orbit should look and then used telescopes to see if their calculations matched what they observed. This worked for all the planets except Uranus. They watched Uranus and saw that its orbit moved almost the way their model predicted, but not exactly.



Two astronomers had the idea that perhaps there was another planet that they had not discovered yet. Such a planet could be pulling on Uranus and making it move strangely, changing its orbit. They added this new planet to their model and calculated where it should be in order to make Uranus move the way it does. When they pointed their telescopes at the calculated position, there was a planet! The new planet was named Neptune, the God of the Oceans in Roman mythology. The discovery of Neptune is an example of how astronomers use their knowledge of force and motion to construct models, and then use their models to predict and explore space.

ACTIVITY 7.3 – NEWTON'S FIRST LAW

What Will We Do?

We will analyze the way a marble moves as it rolls in a metal spiral.

Procedure

Your teacher rolled a marble inside a metal spiral. The ball rolled in a predictable manner while it was inside the spiral but not so predictably when it left the spiral.

1. What forces act on the marble when it is in the spiral? Make a free-body diagram showing the marble and these forces.

2. Why does the marble change direction while it rolls along the spiral?

3. What forces act on the marble when it leaves the spiral? Make a free-body diagram showing the marble and these forces.

4. Why does the marble roll in the direction it does after leaving the spiral?

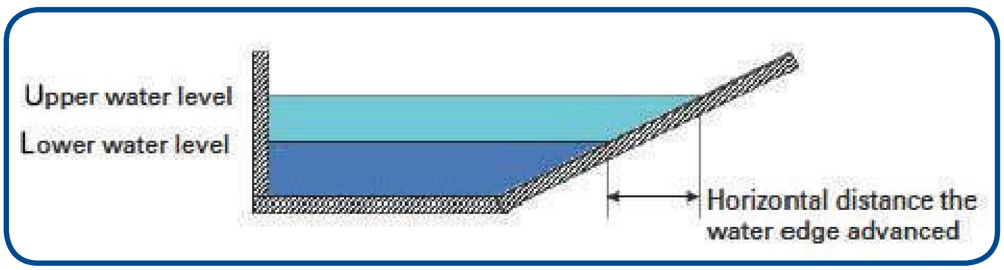
Reading 7.3 – Tides

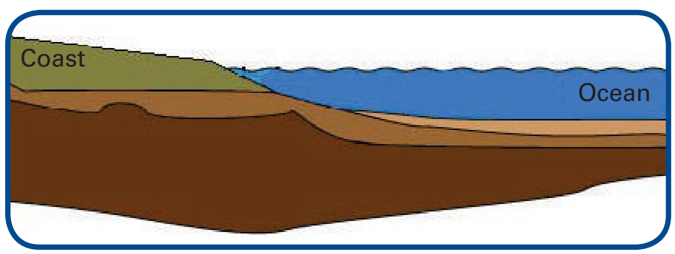
Getting Ready

If you live near the ocean or have visited one, you know that at some times of day the waves come onto the land farther than at other times. Look at the boat in the photo. How did it get there? Earlier in the day, the water came farther inland, allowing the boat to float to where it is in this photo. Later, the water stopped coming so far inland, leaving the boat where it is on the ocean bottom. This happens at many places that have beaches but not on all beaches. At places where this happens, the waves come in farther twice a day, instead of only once. What makes this happen? What does this have to do with forces? This following reading describes more about this phenomenon, which is called a *tide*.

How Does the Ocean Reach Farther Inland?

Imagine you have a large basin with a side that rises at an angle. The baby bathtub in this image is an example. You fill the tub slowly with water by adding the water to the middle of the tub. As the water level rises, the edge of the water moves outward, up the back of the slanted side. This drawing also illustrates what happens. The edge of the water's surface moves out horizontally as the water level rises.





Just as the back of the baby bathtub rises gradually, so does the ocean floor as it reaches a coast.

1. When does the edge of the water advance farther inland—when the ocean's floor is a gradual slope or a steep slope? Why? (Drawing two different slopes might help you think about this.)

For the ocean to reach farther inland, the level of the water must rise. How is it possible for the level of the ocean to change?

What Makes the Ocean Level Change?

People often think of an ocean as flat, but because the Earth is round, the surface of oceans is also round, like a ball. Most people also think of Earth as a solid ball, but most of Earth is not land; it is covered by water. The continents on which people live are actually huge islands almost completely surrounded by oceans. Look at this map of North America. Except for the narrow strip of land (Central America) that connects it with South America, it is surrounded by water. On different sides, the land is touched by the Pacific Ocean, the Atlantic Ocean, and the Arctic Ocean. These oceans are connected to each other, so water flows from one to the other.

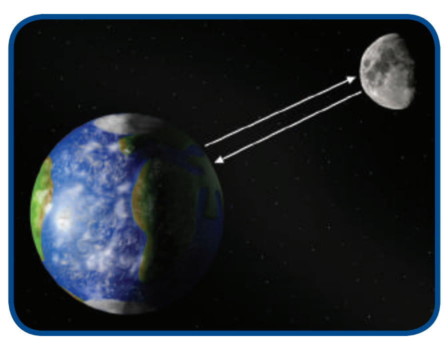
The total amount of water in the oceans does not change. That has to mean that if the level of an ocean rises at one place because there is water flowing to that place, then the ocean level must go down at another place because there is water flowing away from that place. When the water level is high, it is called high tide, and when it is low, it is called low tide.

2. Can high tide occur everywhere in the world at the same time? Explain.

Why do the ocean levels change? What makes them higher and lower at different times? You may be surprised to learn that the answer has to do with the moon.

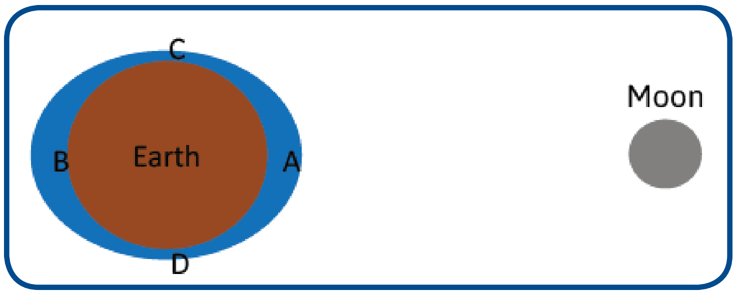
How Does the Moon Cause the Tide?

You have learned that any two objects attract each other with a gravitational force. The gravitational force between two objects is very small unless the mass of at least one of the objects is very large. Earth orbits the sun because of the gravitational force between Earth and the sun. Likewise, the moon revolves about Earth because of the gravitational force between Earth and the moon, but you have also learned that every force comes in pairs, so if Earth pulls on the moon, the moon must also pull on Earth.



3. Which force is greater—Earth's gravitational pull on the moon or the moon's gravitational pull on Earth? Explain.

Besides making objects change their motion, forces also make objects change their shape. The moon is solid; therefore, Earth's gravitational force has only a very little effect on the moon's shape. Likewise, the moon's gravitational pull should have very little effect on Earth's shape. However, most of Earth's surface is covered with water, and water can change its shape very easily.



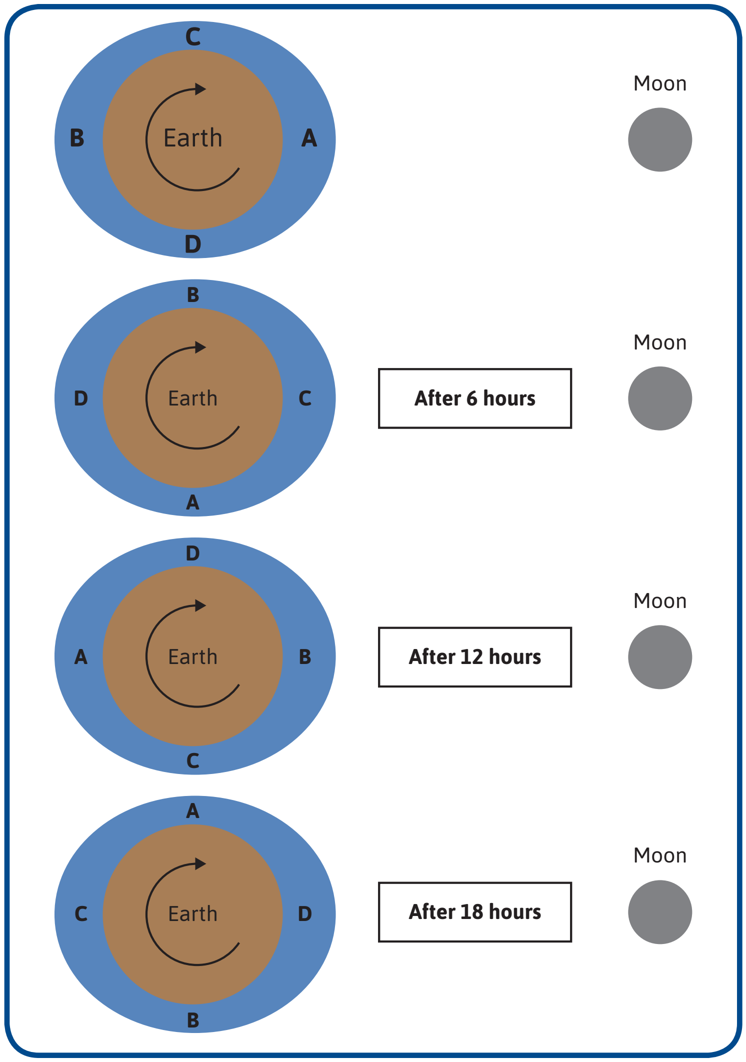
The solid Earth barely changes its shape, but the water covering Earth does change its shape. Instead of having the shape of a ball, the water gets a shape that looks something like a football. The football-shaped water always points toward the moon because it is the moon's gravitational pull that causes the football shape to occur.

Notice that in the model of Earth surrounded by water, there are two places where the water is deep (A and B) and two places where the water is shallow (C and D). A and D are the places on Earth where there is a high tide (the level of the ocean is high), while C and D are the places on Earth where there is a low tide (the level of the ocean is low). It is the moon's gravitational pull on Earth that causes the ocean's level to rise and fall; scientists refer to this phenomenon as *tides*.

Why Are There Two High and Two Low Tides Every Day?

The figure of Earth surrounded by water is a model, meaning it shows only some of a phenomenon's features but it does not represent other features. One of the features the model does not show is that Earth rotates on its axis every 24 hours. This means that if the model showed the phenomenon at a different time, points A, B, C, and D would no longer have been located where they are shown in this model. The next model, which is more complicated than the previous one, shows the following:

Here we see that although Earth rotates, the ends of the football always point toward the moon. While point A has a high tide, after 6 hours it has a low tide; after 12 hours, it has a high tide again; and after 18 hours, it again has a low tide. Every place has two high tides a day and two low tides.



4. What other features are now shown by the model that might be relevant to understanding how tides occur?

Do You Want to Learn More?

For the tides to occur, there has to be a place for the extra water to come from during high tide and to go to during low tide. Bodies of water that are surrounded by land, such as lakes or seas, do not have any place that is far enough away from which to take their extra water. One place has to be at high tide and the other at low tide; so they need to be about a quarter of the way around Earth from each other. So beaches on the Great Lakes, Salt Lake, and Lake Tahoe do not have tides. However, beaches on the Atlantic and Pacific coasts do have tides.

Lesson 8

Using Forces and Energy to Understand the Magnetic Cannon

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.

1. List the supporting phenomena:

Principle 2: For every force an object applies, there is an equal and opposite force acting on the object.

2. Summarize these two principles as one.

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

4. What makes the hammer stop when it hits the nail?

5. What is the relation between these two forces?

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

6. List the supporting phenomena:

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

7. List the supporting phenomena:

8. Summarize these two principles as one.

9. 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.

10. List the supporting phenomena:

Principle 6: 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.

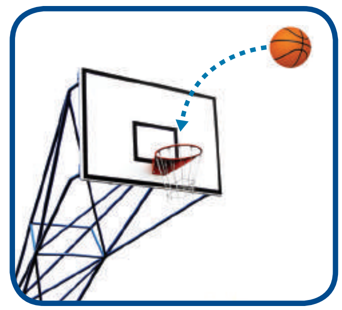
11. List the supporting phenomena:

Principle 7: Unbalanced forces acting on an object change its speed or direction of motion, or both.

12. List the supporting phenomena:

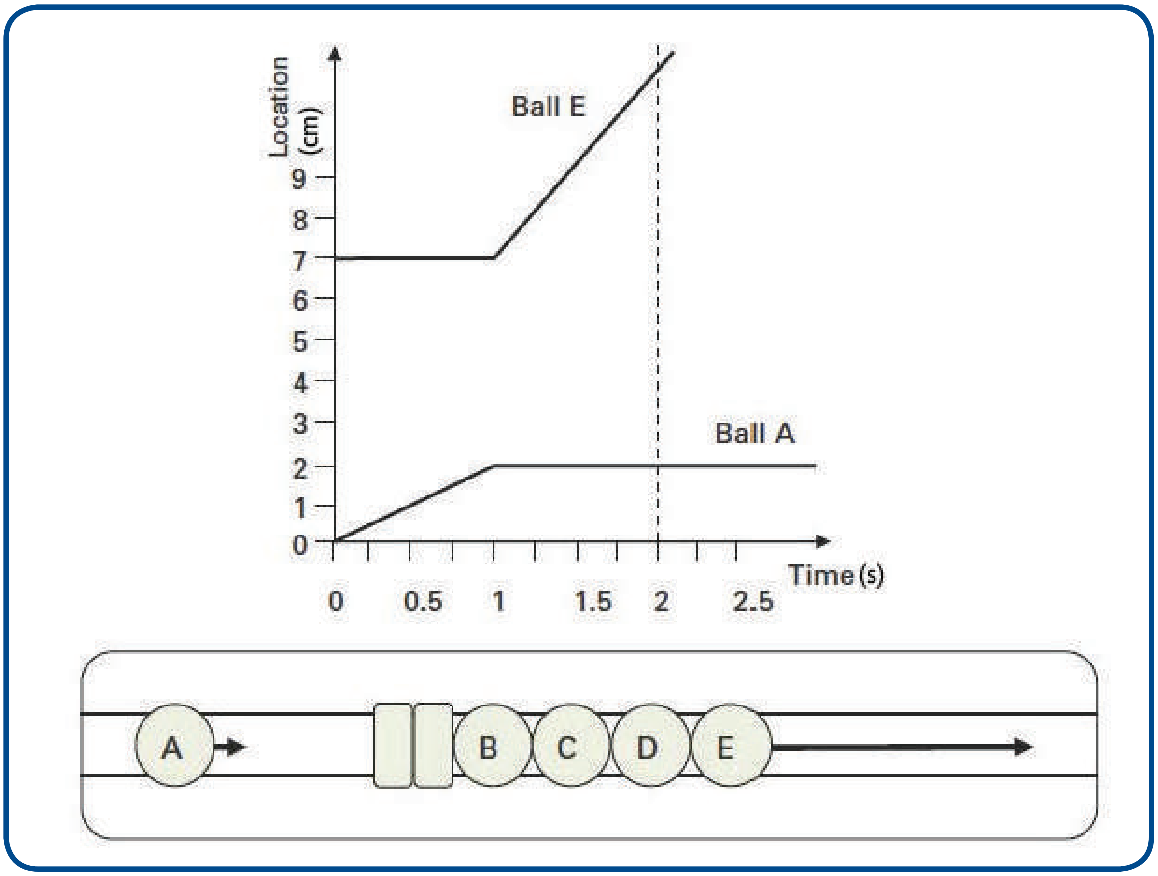
Principle 8: An object will change its speed of motion or direction or both if it is subjected to unbalanced forces, otherwise it will continue to remain at rest or move at a constant speed in a straight line.

13. 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.

1. During the first second:

    - Was each ball moving or motionless?

    - Which forces acted on each ball?

    - Did these forces reinforce or counteract each other?

2. 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.

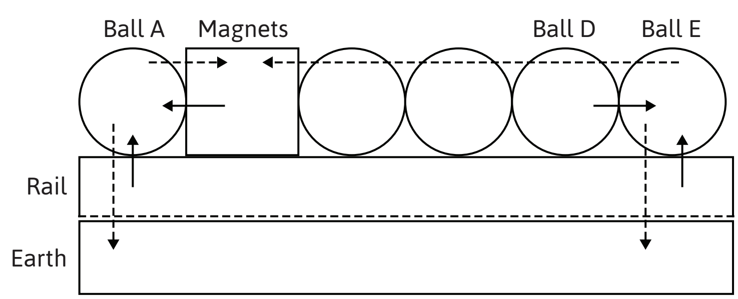
Procedure

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.

1. 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?

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



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

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

5. 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.

6. 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.

7. 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 much faster than 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 question.

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.

	Ball A		Ball E	
	Magnetic Energy	Kinetic Energy	Magnetic Energy	Kinetic Energy
Condition I				
Condition II				

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

2. 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.

Reading 8.4 – The Universe

Getting Ready

Many years ago, a Danish astronomer named Tycho Brahe was making a map of the sky, documenting 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 broad daylight. Brahe kept track of this new star and documented everything he noticed—how it appeared; how it faded; and finally, after 18 months, how it disappeared. Brahe could not explain what he saw.

Today we know that what Brahe observed was a supernova explosion. The explosion actually happened 7,500 years before he saw it. What is a supernova and how could Brahe have seen something that happened in the past?

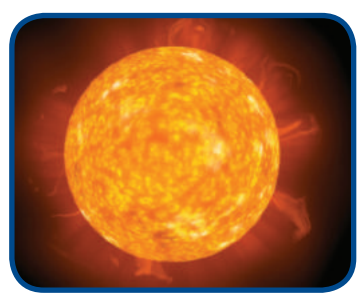
In this reading, you will learn about the stars you see in the sky, about supernovas, and about other interesting objects in the universe.

Stars

How many stars can you see when you look at the sky on a clear night?

Most of the points of light you see in the sky at night are stars. Stars are like the sun; they are huge balls of fire that radiate light. However, they are much, much farther away from Earth than the sun, which is why they appear smaller. There are several types of stars, differing in size, color, temperature, and duration. Small stars usually use their fuel slowly and are therefore relatively cold. On the other hand, because they use their fuel slowly, they also can last for a long time. Relatively cold stars are reddish.

If you have learned about infrared light, you know that different parts of a flame have different colors, and 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 be. You can tell how hot a star is by looking at its color.



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 because they are so small and make very little light.

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

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

Stars are organized in galaxies. 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 stars (a thousand billion). All these galaxies are so far away from Earth that without telescopes, you can see them as no more than a dim, fuzzy spot in the sky. Some of the white points we see 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 they are made up of many stars.

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 grasp when learning about the universe is the numbers, sizes, and distances involved. The universe is huge, almost beyond comprehension, when compared to everything you know from daily life. For example, the closest star to Earth, other than the sun, is about 24,000,000,000,000 miles away. It would take the fastest spacecraft we have developed about 10,000 years to get there—and that is the closest star. Most stars are millions and billions of times farther away than that.

When you start thinking about such immense distances, 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 zeros in them. To measure distances in space, scientists use a unit called a *light-year*.

Light travels at the speed of 186,000 miles per second. That means that in one second, light travels 186,000 miles. A light-year is the distance that light travels in a year. 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.

The closest star to Earth (besides the sun) is about 24,000,000,000,000 miles away. How many light-years away from Earth is it? How long does it take the light it produces to get from it to us?

Look at the following table, which shows the distances between some things in miles and light-years. Explain why people do not use light-years when describing distances on Earth or for objects close to Earth.

The Universe Is Very Old

When you gaze at objects in the night sky, you are looking back in time. 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 it takes its light to reach you, meaning that you are looking further back in time. For example, light from the sun takes 8½ minutes to reach Earth. When you see the sun, you are seeing it as it looked 8½ minutes 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.

	Miles	Light-Years
Los Angeles (California) – New York (New York)	2,450	0.0000000004
New York (UAS) – Beijing (China)	8,112	0.000000001
Earth – moon	238,857	0.00000004
Earth – sun	91,000,000	0.00001548
Earth – Andromeda galaxy	14,696,249,500,000,000,000	2,500,000

When Brahe saw a new star appear in the sky, he was looking 7,500 years into the past. How far away was that star from Earth?

Astronomers estimate that the universe first appeared about 13 billion years ago. For comparison, scientists estimate that humans first appeared only about 200,000 years ago.

The Universe Is Constantly Changing

Observations show that the universe is expanding, meaning that the galaxies are getting farther and farther away from each other. This means that if we could go back in time, we would see that the galaxies were closer to each other than they are now. About 13 billion years ago, all the galaxies would be at the same place. What happened before that? Scientists think that the entire universe began in a Big Bang, a gigantic explosion, with everything flying out in all directions, making the universe expand.

Not only is the universe expanding, but stars are born and die all the time. Earth and the sun were not always there, and moreover, they will not always be there. 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. The new star that Brahe saw was dead long before he saw it. How did it die?

How Do Stars Die?

Stars do not actually burn fuel and produce fire. You have learned that burning is the result of a chemical reaction in which oxygen combines with other substances. The process that makes stars burn is called a nuclear reaction instead of a chemical reaction. The fire you see on stars is the outcome of hypothetical giant hydrogen bombs exploding. A star's fuel is usually the hydrogen it contains, and when a star's hydrogen begins to end, the star gets colder and goes through a series of changes. Each type of star undergoes a different series of changes leading to its death.

Yellow stars, like the sun, are medium-sized stars, which are fairly hot. They live about 10 billion years. Near the end of their lives, these stars expand, becoming much larger than they originally were. When this happens to the sun, it will expand so much that it will reach Earth. (Astronomers estimate this will happen in about 5 billion years.) Eventually the sun will shrink again and become a white dwarf, and then die. While shrinking, white dwarfs shed their outer layers and leave behind a beautiful cloud of gas, such as the one you can see in this photo.

Some stars, usually large ones, die in a spectacular way. They grow larger just like yellow stars, but instead of shrinking, they explode in what is called a supernova. Supernova explosions can be brighter than an entire galaxy and can be seen from very far away. What Brahe noticed in 1572 was a supernova. He saw light that was emitted during the explosion.

What happens after a star explodes? Sometimes the explosion blasts away the entire star, leaving a gigantic cloud of gases and debris behind. In other cases, a core of the star is left behind, and it begins to get smaller. It might contract so much that is becomes the size of a tennis ball or even smaller. Sometimes it contracts so much that it totally disappears. It could become smaller than a single atom. When it gets so compact and so dense, all the light that reaches it is absorbed, none is scattered, so it cannot be seen at all. Something that scatters no light at all appears black, so these stars are called black holes.

What We Do Not Know about the Universe

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

Summary

This reading contains a lot of information about different objects in the universe. In order to organize what you learned about them, make a list ordering them from biggest to smallest, and then write one or two sentences summarizing their main characteristics.