



# 17A Planets in Motion

## How do the planets move?

How fast can you go? Actually, every second you travel 18.5 miles through space! That's right, 18.5 miles per second, or 1110 miles in one hour! And as a passenger on the planet Earth, each year you travel approximately 600 million miles along the Earth's orbit around the Sun, held in orbit by gravity. And while you are traveling at these vast speeds through space you are spinning in circles! And you are not alone. Alongside you is an orbiting moon. There are other planets traveling at different speeds too, following different orbits. Some closer to the Sun, and some further away. In this investigation, you will develop a greater understanding of the Earth's rotation on its axis and the Earth's revolutions around the Sun. Then you will compare the Earth's motions to other planets.

### Materials

- 4 working flashlights
- Masking tape
- Black electrical tape
- Large open space for part 1 and 2
- Classroom clock

## Part I: The Earth's movements

### 1 Setting up

Earth has two particular motions: rotation and revolution. The rotation of Earth is its movement as it spins on its axis. One full rotation takes 24 hours. The revolution of Earth is its movement along its orbit around the Sun. Held in orbit by gravity, it takes Earth 1 year to make one full revolution.

1. Place 4 students back to back in the circle of masking tape in the center of the room. Turning the flashlight on, each student should face outward. These students represent the Sun.
2. All other students step on the black electrical tape and spread out around the circle. This tape represents the elliptical orbit Earth takes around the Sun and each student represents the Earth. Note: Earth tilts on its axis at a  $23.5^\circ$  angle.
3. Darken the room.
4. Follow the teacher's directions.

### 2 Doing the activity

1. Each student representing Earth should rotate on his/her axis.
2. Use the classroom clock and calculate how long it takes you to make one full rotation. How long does it take Earth to make one full rotation?
3. Rotate slowly. Stop when it is nighttime on your Earth.
4. Continue to rotate. Stop when it is daytime on Earth.
5. Continue to rotate. Stop when the Sun is just about to set on your Earth.
6. Each student stops rotating.

7. Begin revolving around the Sun in a counterclockwise direction. Do not bump into any other students.
  8. Use the classroom clock and calculate how long it takes to make one full revolution. How long does the real Earth take to make one revolution?
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9. Begin to revolve and rotate.
10. Make one full revolving rotation.
11. After one full revolving revolution, all students return to your seats.

**Part 2: All the planetary movements**

**3 Setting Up**

Our solar system primarily consists of the Sun and 8 known planets. Each planet rotates on its axis and revolves around the Sun. However, each planet rotates and revolves around the Sun at different speeds and along different orbits.

Examine Table 1 to learn about the movements of the planets. Circle any rotation or revolution times that are faster than the planet Earth.

**Table 1: Rotation and revolution times of each planet**

Planet	Length of time for one full rotation on its axis	Length of time for one full revolution around the Sun
Mercury	59 days	88 days
Venus	243 days	225 days
Earth	1 day	365.25 days
Mars	24.6 hours	687 days
Jupiter	10 hours	11.9 years
Saturn	10.7 hours	29.5 years
Uranus	17 hours	84 years
Neptune	16 hours	165 years



#### 4 Doing the activity

1. The center circle of masking tape will represent the Sun.
2. One student will be selected to represent the Earth. That student should step on the black electrical tape and begin rotating and revolving.
3. The planets are listed in their order from the Sun. Remember the speed of your rotation, the location, in comparison to the Earth. Once you have decided on your planet, choose a direction.
4. Using the Earth as a reference point, all other planets should move in the same direction where they think their planet would belong. Record the most accurate speed.

#### 5 Thinking about what you observed

- a. Describe the difference between rotation and revolution. Include a diagram if it is helpful.

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- b. Explain how rotation results in day and night.

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- c. Which planet has the slowest rotation? Use a calculator to determine how many hours one day would take.

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- d. Which planet do you think moves the most similarly to Earth? Provide evidence for your choice.

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- e. What is incorrect about the comment, "The Sun is racing across the sky"?

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- f. Predict: The Sun has a larger mass than Earth and a gravitational pull on Earth. Because Earth is moving forward at a rapid speed, it is not directly pulled into the Sun; it stays in an orbit around the Sun. Predict how Earth would travel differently if the Sun became small enough so that it no longer had the gravitational pull on Earth.

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# 17B Solar System

## How big is the solar system?

It is difficult to comprehend great distances. For example, how great a distance is 140,000 kilometers (the diameter of Jupiter) or 150,000,000 kilometers (the distance from the Sun to the Earth)? An easy way to compare these distances is to create a *scale model*. For instance, a globe is a scale model of Earth and road maps are scale models of geographic regions. These scale models help us visualize the true sizes of objects and the distances between them.

In this investigation, you will compare an astronomical distance—like the distance from the Sun to Neptune—to a measurable distance—like the length of a football or soccer field. Using proportions, you will make a scale model of the distances of the planets from the Sun.

### Materials

- Access to a large space with a length of 100 meters (a soccer field is ideal)
- A metric tape measure or a trundle wheel
- A variety of objects to represent the relative sizes of the planets (examples: softball, soccer ball, bowling ball, small plastic balls, inflatable beach balls). To represent the Sun and some of the larger planets may require imagination.
- Blank paper for making signs
- A simple calculator

## 1 Using proportions to determine scale distances

Neptune is an average distance of 4.5 billion kilometers from the Sun. We can use a proportion to determine a scale distance for our model. Assume the largest distance you can measure is 100 meters. The length of a soccer field is usually between 90 and 120 meters long. For this investigation, we will use 100 meters as the scale distance between the Sun and Neptune.

$$100 \text{ m} = 4,500,000,000 \text{ km}$$

If the distance from the Sun to Neptune equals 100 meters, where would you find the other planets? You can answer this question by setting up the following proportion where  $x$  is the distance from the Sun to any planet, in meters:

$$\frac{x}{\text{Distance of the Sun to planet}} = \frac{100 \text{ m}}{4,500,000,000 \text{ km}}$$

Mercury is 58,000,000 kilometers from the Sun. Using our proportion, we can find the scale distance:

$$\frac{x}{58,000,000 \text{ km}} = \frac{100 \text{ m}}{4,500,000,000 \text{ km}}$$

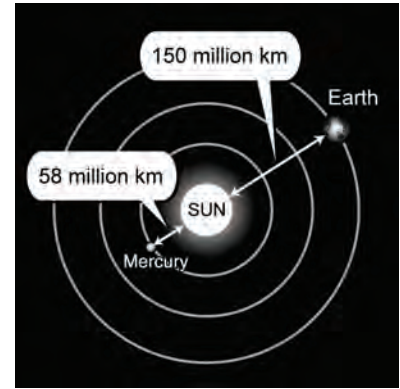
Cross-multiply and rearrange the variables to solve for  $x$ :

$$x = \frac{100 \text{ m}}{4,500,000,000 \text{ km}} \times 58,000,000 \text{ km} = 1.29 \text{ m}$$

**Mercury is 1.29 meters from the Sun using this scale.**

## 2 Determining scale distances for the other planets

Based on the example in Part 1, you would place Mercury 1.29 meters or 129 centimeters from the Sun in your 100-meter scale model. Use this example to help you calculate the placement of the other planets. Write the distance in meters for each planet in Table 1,

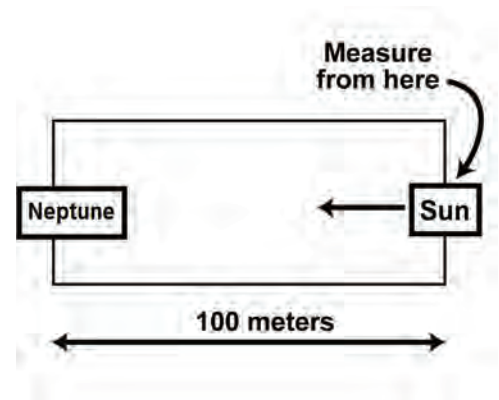


**Table 1: Distance from the Sun**

Planet	Actual distance to Sun (km)	Proportional distance from the Sun (m)
<b>Mercury</b>	<b>58,000,000</b>	<b>1.29</b>
Venus	108,000,000	
Earth	150,000,000	
Mars	228,000,000	
Jupiter	778,000,000	
Saturn	1,430,000,000	
Uranus	2,870,000,000	
Neptune	4,500,000,000	

## 3 Setting up the scale model

1. To begin, make signs for each of the planets and one for the Sun. In your scale model, a student in your class will hold the sign at each position of the planet.
2. In an area that is at least 100-meters long, identify the location of the Sun. A student will stand in this position with a sign that says "Sun."
3. Measure 100 meters from the position of the Sun. At the 100-meter mark, a student will stand with a sign that says "Neptune." In this model, 100 meters is the scale distance from the Sun to Neptune.





4. Now, use the scale distances from Table 1 to find the locations of each planet. At the location of each planet, a student will stand with the appropriate sign. Then, answer the questions.

a. After constructing a model of it, what is your impression of our solar system?

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b. Describe some disadvantages and advantages to this model of the solar system.

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c. Alpha Centauri is the closest star to Earth at 274,332 AU. One astronomical unit is equal to 150 million kilometers. Where would you place this star in the 100-meter scale model?

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d. The diameter of the Milky Way galaxy is known to be about 100,000 light years. One light year is 63,000 AU. How does the Milky Way compare using the 100-meter scale model?

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#### 4 Determining scale sizes of the planets

Mercury has a diameter of 4,880 kilometers. How big would Mercury be in your 100-meter scale model? You can use the same method to determine the scale diameter of Mercury that you used in Part 2:

$$\frac{x}{4,880 \text{ km}} = \frac{100 \text{ m}}{4,500,000,000 \text{ km}}$$

Cross-multiply and rearrange the variables to solve for  $x$ :

$$x = \frac{100 \text{ m}}{4,500,000,000 \text{ km}} \times 4,880 \text{ km} = 0.000108 \text{ m}$$

Based on the example above, the diameter of Mercury in a 100-meter scale solar system would be 0.000078 meters or 0.078 millimeters. For comparison purposes, a single human hair is about 0.1 millimeters in diameter or one-tenth of a millimeter.

Use the above proportion to calculate the diameters of the other planets as well as the Sun and Earth's moon. Write these values in units of meters in the third column of Table 2.

**Table 2: Diameters of the planets, our moon, and Sun**

Planet	Actual diameter (km)	Scale diameter (m)	Scale diameter (mm)
Sun	1,391,980		
Mercury	4,880	<b>0.000108</b>	
Venus	12,100		
Earth	12,800		
Moon	3,475		
Mars	6,800		
Jupiter	142,000		
Saturn	120,000		
Uranus	51,800		
Neptune	49,500		

Now, answer these questions.

- How big is the Sun in this model in units of centimeters? \_\_\_\_\_
- How much larger is the Sun's diameter compared with Earth's? How much larger is Earth's diameter compared with the moon's?

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- The smallest object that the human eye can see without magnification is 0.100 millimeters. Given this information, which planets would be visible to the human eye? Would you be able to see the Sun or the moon on this 100-meter scale model of the solar system?

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- What is your impression of how the size of the planets and the Sun compare with the size of the solar system?
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## 5 Extension: Making a larger scale model of the solar system

In this part of the investigation, you will use common objects to compare the diameters of planets, the Sun, and Earth's moon in our solar system. For example, an Earth globe can represent the scale size of Earth. The diameter of the globe we will use is 30 centimeters.

1. If an Earth globe is used to represent the size of Earth, what would the sizes of the Sun and the other planets be? How big would the moon be? Use what you have learned in this investigation to calculate the scale diameters of the other planets, the moon, and the Sun. Fill in the third column of Table 3 with these values.
2. What objects could be used to represent each of the planets, the moon, and the Sun? Fill in the fourth column of Table 3 with your answers to this question.

**Table 3: A scale model of the solar system**

Planet	Actual diameter of planet (km)	Scale diameter of Sun or planet (cm)	Representative object and its diameter or length (cm)
Sun	1,391,980		
Mercury	4,880		
Venus	12,100		
<b>Earth</b>	<b>12,800</b>	<b>30 cm</b>	<b>Earth globe, 30 cm</b>
Moon	3,475		
Mars	6,800		
Jupiter	142,000		
Saturn	120,000		
Uranus	51,800		
Neptune	49,500		

Now, answer these questions:

- a. How many times greater is 30 centimeters than 0.284 millimeters? These are the diameters of Earth for the two scale models you created.

- b.** Using your answer to question 5a, what would be the distance between the Sun and Neptune on this larger scale? Come up with a way to explain or model this distance.

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- c.** Why is it challenging to make a scale model of the solar system that includes the distances between planets and the Sun and the sizes of the planets?

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# 18A Days and Months

## What are days and months?

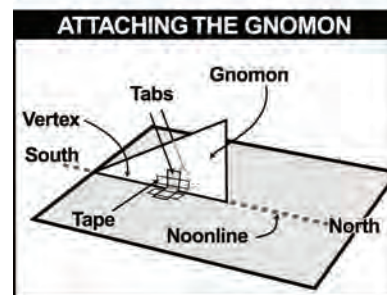
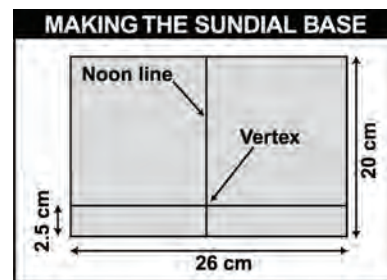
Measurement of days and months depends on the cycles between Earth and the Moon and Earth and the Sun. Therefore, it is not surprising that some of the first clocks were sundials based on the movement of shadows as the Sun appeared to move across the sky. A sundial is a large timepiece on the ground. The “hand” of the clock to the right is a shadow created by an obelisk. In this investigation, you will build a sundial, and then calibrate it so that you use it to accurately tell the time. You will also model the lunar cycle and then observe it over the course of a month.

### Materials

- A protractor
- Two pieces of 20-by-26-centimeter cardboard (or a file folder)
- Scissors
- Small metric ruler
- Tape
- Navigational compass
- A flashlight
- A 2-or-3 inch foam ball
- A pencil or popsicle stick

## 1 Building a sundial

1. Obtain a cardboard folder from your teacher. To build your sundial, measure and cut out a 20-by-26 centimeter size piece of the folder. First, draw one line dividing the piece in half. This will be the noon line. Then, draw a perpendicular line 2.5 centimeters from one edge. The place where the two lines intersect will be called the vertex.
2. Next you need to make the *gnomon*, the part of your sundial that casts a shadow. On another piece of the folder, mark off a baseline that is 10 centimeters long. Then, using your protractor, make an angle with this line that is equal to the angle of your particular location’s latitude on Earth. Your teacher will give you the correct latitude. Then, draw a second line, perpendicular to the baseline and making a right triangle. Write the angle for your latitude in the position shown on the diagram.
3. Cut out your gnomon. Then, attach the gnomon so that it is perpendicular to the base of the sundial. To keep the gnomon upright, cut out two rectangular tabs. Tape these to each side of the gnomon and fold them out in opposite directions. Then, tape them to the base of the sundial as shown.
4. Bring your sundial outside on a sunny day. Use a compass to help you point the noon line to the north.
5. Now, answer the questions on the next page.



a. Do you see a shadow on the sundial? Where is it located? \_\_\_\_\_

b. What will happen to the shadow as the day progresses? Explain your answer.

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c. Can you tell the time by looking at the location of the shadow on the sundial? What do you need to do in order to be able to tell the time?

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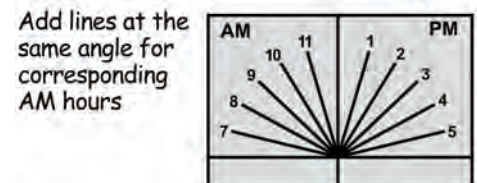
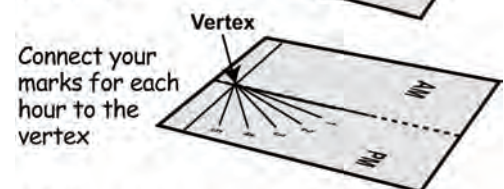
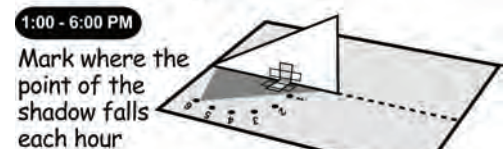
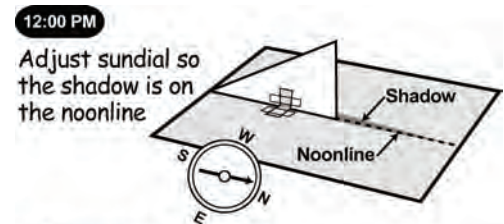
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## 2 Calibrating the sundial

In order to tell the time accurately with your sundial, you need to calibrate it. You will need a few hours on a sunny afternoon to complete this part of the investigation.

1. Take your sundial outside at noon on a sunny day. Use a navigational compass to point the noon line on the sundial toward the north.
2. Move the sundial slightly to the right or left until the point of the gnomon's shadow is resting on the noon line.
3. Use the compass to determine the exact direction that the noon line is pointing, and write it down.
4. Leave your sundial for exactly one hour. Go back and mark where the point of the gnomon's shadow is located on the sundial. Write the time (1:00 pm) next to this mark.
5. Repeat the fourth step five more times (until the actual time is 6:00 pm). You should have a mark for each hour after noon from 1:00 until 6:00.
6. Take your sundial indoors. Use a ruler to connect each point to the vertex as shown. You have now calibrated your sundial to measure time from noon until 6:00 pm.
7. Use a protractor to measure the angle between the noon line and the 1:00 line. Record this angle in Table 1.
8. Measure the other angles from the noon line to each of the other marks and record the angles in Table 1.
9. To calibrate the morning hours, you will use the same angles you measured for the afternoon hours. Table 1 will help you determine which angle to use for each morning hour.





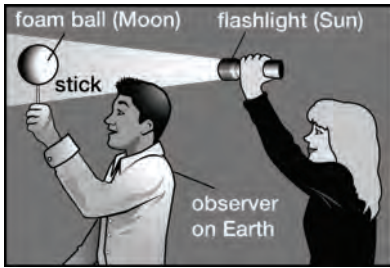
10. Test your sundial on another sunny day. To do this, make sure you use a compass to point the noon line in the direction you recorded earlier.

**Table 1: Calibrating the sundial**

Afternoon hour	Angle from noon line	Corresponding morning hour
1:00 pm		11:00 am
2:00 pm		10:00 am
3:00 pm		9:00 am
4:00 pm		8:00 am
5:00 pm		7:00 am
6:00 pm		6:00 am

- a. Can you use your sundial to tell the time? How accurate is your sundial?
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- b. How could you improve the accuracy of your sundial so you could tell the time within fifteen minutes?
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- c. What variables affect the accuracy of your sundial? List as many variables as you can think of.
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- d. What effect do you think that the time of year will have on the accuracy of your sundial? Explain your answer.
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- e. How do you think Daylight Savings Time will affect the accuracy of your sundial? How could you adjust the sundial for this?
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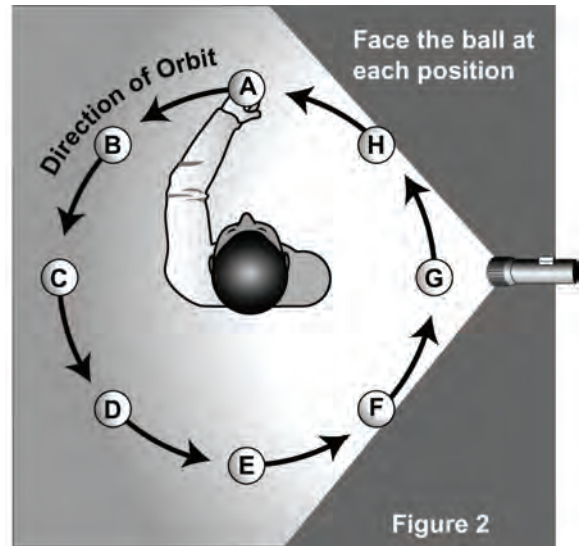
### 3 Modeling the lunar cycle



A sundial is an instrument that allows you to keep track of time during the day. Ancient civilizations used the Moon to keep track of the passage of each month. The Moon revolves around Earth in a counterclockwise direction. As it revolves, its appearance from Earth changes in a repeating pattern called the lunar cycle. In this part of the investigation, you will model the lunar cycle. You will work with another student, as shown in Figure 1.

**Note: Your teacher will turn out the classroom lights once you have gathered your materials.**

1. Place a foam ball on a pencil or stick. This ball represents the Moon.
2. Have another student hold a flashlight. The flashlight represents the Sun. Your head represents Earth.
3. Hold the ball above your head, at arm's length from your face. Stand about one meter from the flashlight, which is held at the same level as the ball.
4. Observe the Moon in each of the positions shown in Figure 2. Face the ball at each position.
5. For each position, indicate how much of the ball is dark and how much is illuminated, in the table below. Use a pencil to show the shaded regions.



**Table 2: Modeling the lunar cycle**

Position	Appearance	Position	Appearance
A		E	
B		F	
C		G	
D		H	



- a. Compare your observations to the diagram of the Moon phases in the student text. Based on your observations, what do the terms waning and waxing mean?

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- b. During what position on Figure 2 would a solar eclipse occur? During what position on Figure 2 would a lunar eclipse occur?













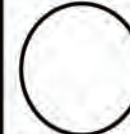






















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#### **4 Long-term project: Constructing a lunar calendar**

Now, you will track time by following the phases of the Moon. In the chart below, draw the Moon as it appears in the sky each night for 28 nights. Record the date of your observation, the time, and illustrate the shape of the Moon for each night. Identify the phase of the Moon for each night. Refer to Cycles on Earth in your student text for a graphic that shows each phase. Use the following two-letter symbols to represent each phase: new Moon (NM), waxing crescent (XC), first quarter (FQ), waxing gibbous (XG), full Moon (FM), waning gibbous (NG), third quarter (TQ), waning crescent (NC)

SUN	MON	TUE	WED	THUR	FRI	SAT
 Date ____ Time ____ Phase ____	 Date ____ Time ____ Phase ____	 Date ____ Time ____ Phase ____	 Date ____ Time ____ Phase ____	 Date ____ Time ____ Phase ____	 Date ____ Time ____ Phase ____	 Date ____ Time ____ Phase ____
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# 18B Earth's Seasons

## What causes the seasons?

In this investigation, you will use a solar cell and a digital meter to measure the intensity of light emitted by a light source that represents the Sun. You will first measure the intensity of light from the bulb at different distances from it—like Earth at different distances from the Sun. Then you will measure the intensity of light at various latitudes on the globe. By performing these two kinds of measurements, you will determine which factors cause the seasons.

### Materials

- Globe
- Velcro® tabs
- 100-watt light source
- Solar (PV) cell
- Digital meter
- Tape measure or meter stick

## 1 Setting up

1. A light source representing the Sun will be placed in the center of your classroom. It is important that the light source emit light equally in all directions like the Sun does.
2. The globe will be used to represent Earth. Put the Velcro® dots on Earth so that the solar cell will adhere to the dots. Put the tabs at the equator, Tropic of Cancer (23.5 degrees north), and Tropic of Capricorn (23.5 degrees south).
3. With your class, choose a wall in your classroom that will represent the position of the North Star (Polaris) in the night sky. Tape a sign to this wall that says “North Star.”

**Safety Note: If your light source is a light bulb, do not touch it. Light bulbs can get very hot!**

## 2 Stop and think

Earth's orbit around the Sun is slightly elliptical. At certain times during the year, Earth is a little closer to or farther from the Sun than at other times. Also, Earth is tilted as it moves around the Sun.

- a. Come up with a hypothesis stating why you think the seasons occur.

*Do you think they are caused by changes in Earth's distance from the Sun?*

*Do you think Earth's tilt causes the seasons?*

*Do you think both of these factors play a role? Or do you think other factors cause the seasons?*

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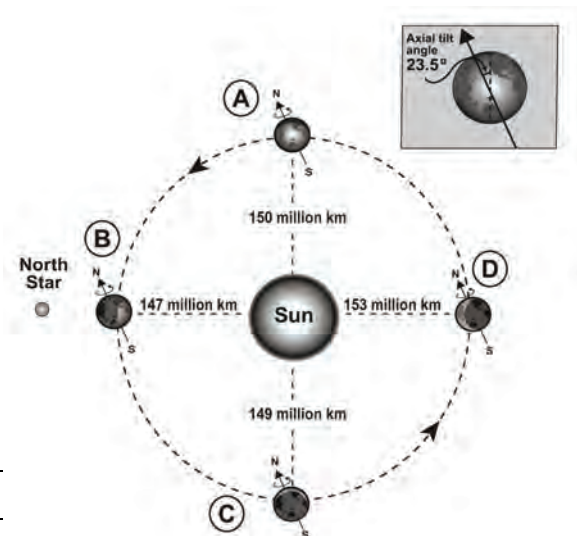
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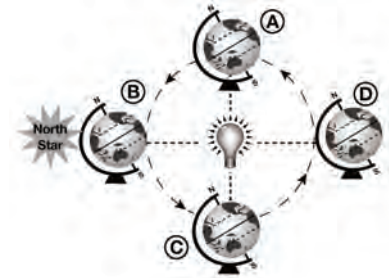
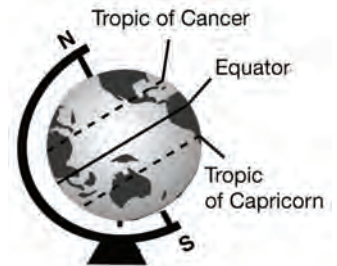
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- b. Which quarter of the diagram (A to B, B to C, C to D, or D to A) do you think represents summer in the northern hemisphere? Explain why you think this is so.

### 3 Doing the experiment, part A (complete with your class)

1. One student will move the globe, in a circle, to each position (A-D) in a counterclockwise direction around the light source (the "Sun"). This movement simulates one revolution around the Sun (or one year).
2. As the globe is moved from point to point, the axial tilt at the north pole of the globe should always point toward the "North Star."
3. As Earth revolves around the Sun, it also spins on its axis. Note that the globe can also be spun on its axis.
4. Now, answer these questions. Use the globe and the diagram at right to help you.



#### Questions:

- a. Although the axis of Earth is always pointing in the same direction, what is happening to Earth itself as it revolves around the Sun?

- b. What does the side of the globe that faces the Sun represent? What does the side of the globe that faces away from the Sun represent?

- c. Diagram the following parts of the globe: equator, northern hemisphere, southern hemisphere, and latitude lines. At what latitude are you located right now?

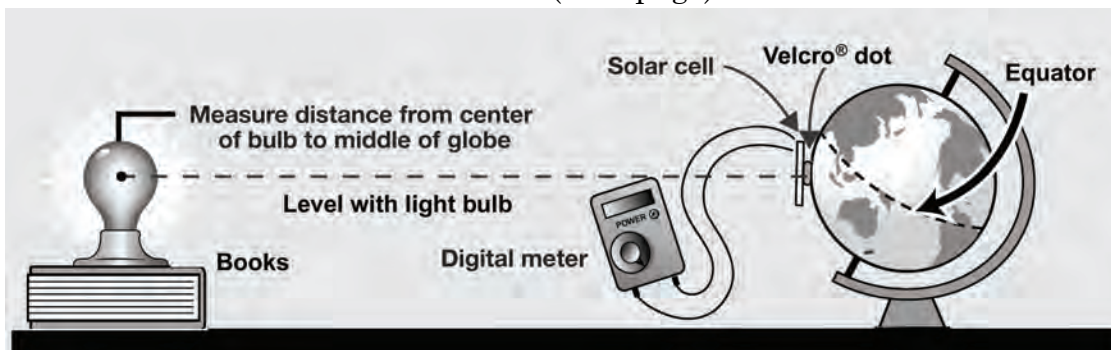
- d. In which position in the diagram is the northern hemisphere pointing towards the Sun? In which position is the southern hemisphere pointing towards the Sun?



#### 4 Doing the experiment, part B

Now, you will model the distance of Earth from the Sun using a scale distance. You will observe the amount of energy (light intensity) produced by a light source at each scale distance. Remember, Earth does not stay the same distance away from the Sun all year long.

It is impossible to measure millions of kilometers in your classroom, but you can use a scale distance of 1 centimeter to represent 1 million kilometers. Therefore, a distance of 150 million kilometers would be represented by 150 centimeters. Using the scale distance of 1 centimeter equals 1 million kilometers, determine the scale distance for positions B, C, and D. Write the scale distance in the third column of Table 1 (next page).



1. Attach the solar cell to the Velcro® dots found on the equator of the globe.
2. Place the globe so the face of the globe is exactly 150 centimeters from the center of the light source. The light source should be level with the center of the globe. One student can hold the end of the tape measure at the center of the globe closest to the light and another directly over the center of the light.
3. Measure the light intensity on the globe using the digital multimeter. Keep the solar cell at the center of the globe so you are only changing the distance of the globe to the light, not the angle of the solar cell. Your readings will be in milliamps (mA). Record your readings in Table 1.
4. Repeat this for the other scale distances, being careful to set the globe at the correct distance for each position A-D. NOTE: Do not move the globe to simulate Earth's orbit for each position. Vary only the distance from the light source.
5. Now answer these questions. Use Table 1 to help you.

**Table 1: Light intensity at scale distances**

Position	Distance from the Sun (km)	Scale distance from the Sun (cm)	Light intensity (mA)
A	150,000,000	150	
B	147,000,000		
C	149,000,000		

**Table I: Light intensity at scale distances**

Position	Distance from the Sun (km)	Scale distance from the Sun (cm)	Light intensity (mA)
D	153,000,000		

**Questions:**

a. Are there big or small differences in distances as Earth revolves around the Sun?

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b. Based on your data, how does the light intensity change as these distances change?

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c. Based on your results from this experiment, do you think Earth's changes in distance from the Sun over a year causes the seasons? Why or why not?

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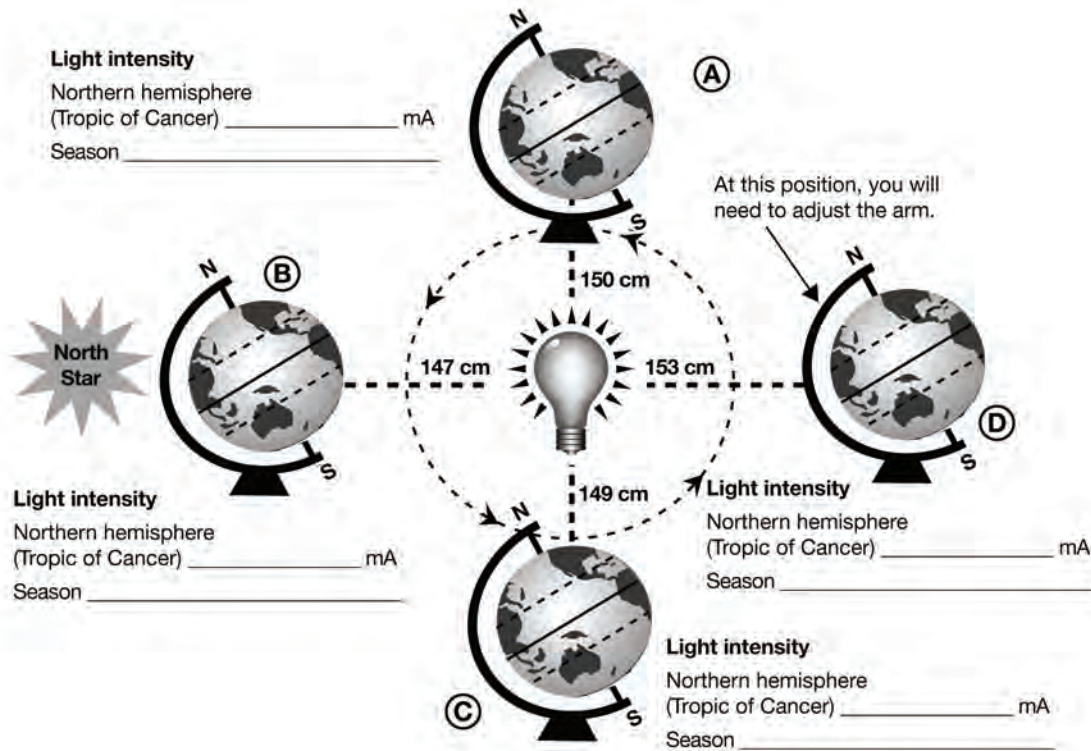
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**5 Doing the experiment, part C**

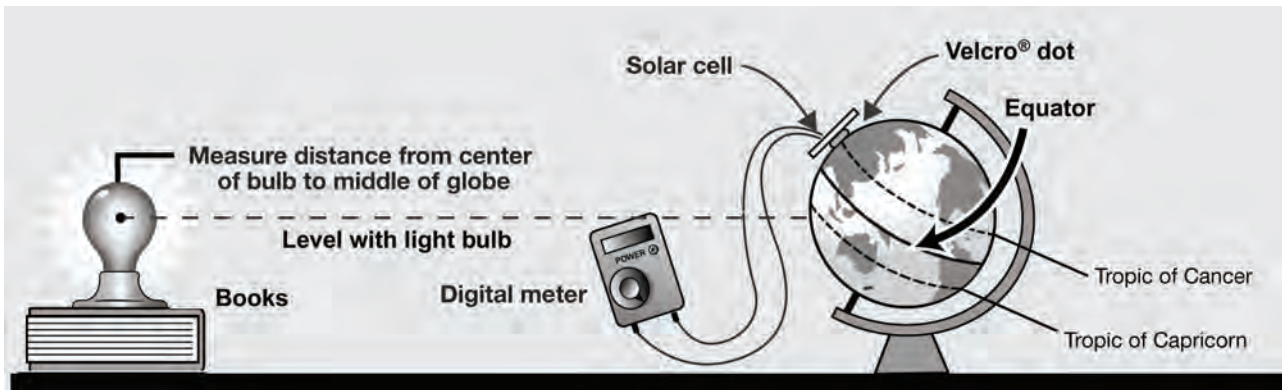
Now, you will simulate the effect that Earth's axial tilt has on the intensity of the Sun's light. You will model Earth's orbit around the Sun, in addition to its distance at the four positions



shown below. Notice how the Sun's direct light never shines further south than the Tropic of Capricorn or further north than the Tropic of Cancer.



1. Since you live in the northern hemisphere, you will place the solar cell on the Tropic of Cancer (23.5 degrees north).



2. At each position, make sure the north pole of the globe always points toward the North Star. Measure each distance from the center of the light bulb to the surface of the globe. You will not move the solar cell this time. The Sun's direct rays will strike the parts of Earth shown by the diagram and you will be able to measure the energy that the Tropic of Cancer receives each time.
  - For Position A, the bulb should be level with the equator and the solar cell will be on the Tropic of Cancer. At this time of year, the Sun's direct rays don't hit the Tropic of Cancer—they hit the equator. The north pole should be pointed at the

North Star. The distance should be 150 cm from the center of the bulb to the globe surface.

- For Position B, the bulb should be level with the Tropic of Capricorn, since during this time of year, the Sun's direct rays hit here. Still leave the solar cell where it is.
  - For Position C, the bulb should be level again with the equator. This is where the direct rays of the Sun shine at this time of year.
  - See if you can figure out Position D on your own. If not, ask a partner or your teacher for help.
1. Write the light intensity values at each position on the graphic. At position D, you will need to move the arm of the globe slightly to the left or right in order to line up the bulb and solar cell.
  2. Answer the questions below and then complete the questions for part 6.

**Questions:**

- a. What role does axial tilt play in the intensity of light on Earth?

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- b. At which position (A, B, C, or D) does the Tropic of Cancer receive the most light? What season do you think that represents?

**6 Thinking about what you observed**

- a. Of the two factors—distance from the light source and axial tilt – which plays the most significant role in causing the seasons? Was your hypothesis supported by your results?

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- b. Based on your results, which position (A-D) represents the first day of summer in the northern hemisphere? Which position represents the first day of winter in the northern hemisphere?

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- c. Which quarter of earth's orbit represents summer in the northern hemisphere (from A to B, B to C, C to D, or D to A)? Explain your answer based on your results from the investigation.

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- d. Now go back to the diagram and write in all the northern hemisphere seasons at the appropriate positions. In the space below, write what would be happening at the same time in the southern hemisphere.

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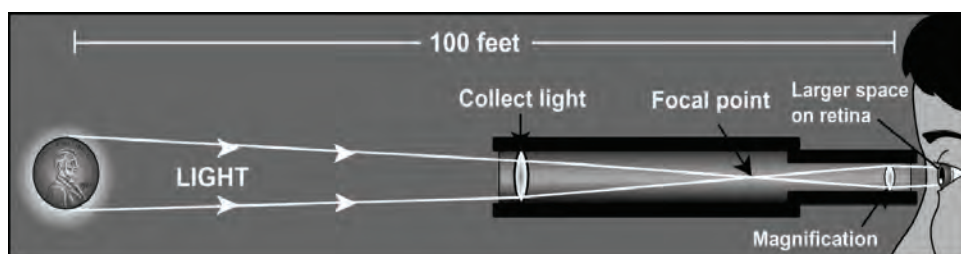
# 19A Tools of Astronomy

## How does a telescope work?

A **telescope** is a device that makes objects that are far away appear to be closer. Telescopes work by collecting the light from a distant object with a lens or mirror and bringing that light into a concentrated point, called a **focal point**. The bright light from the focal point is then magnified by another lens (the eyepiece) so that it takes up more space on your retina (the light-sensing membrane of the eye). This makes the object appear to be larger and closer. In this investigation, you will identify the parts of a simple telescope and learn how it works. You will then use your telescope to observe features on the Moon including craters and maria (the Latin word for “seas”).

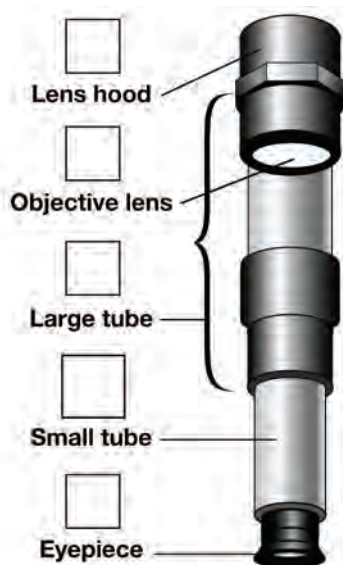
### Materials

- Telescope
- 3 × 5 inch index card
- Metric tape measure (at least 10 meters)
- Ruler with millimeter divisions
- Graph paper
- Simple calculator



## 1 Learning the parts of a refracting telescope

For this investigation, you will use a small refracting telescope. This type of telescope uses a lens to gather light into a focal point, and another lens to magnify the image. Use the diagram below to identify the parts of your telescope. You may take your telescope apart and reassemble it to learn the parts. The function of each part is listed next to the diagram. Place the letter of each function next to the correct part.

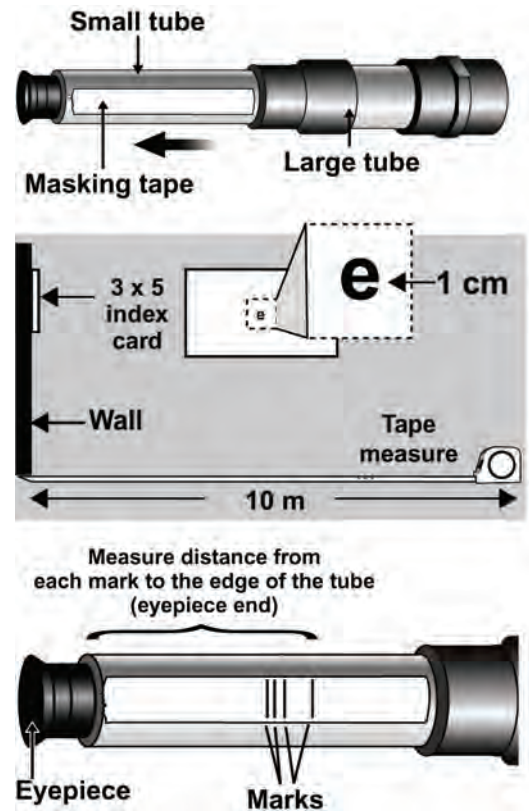


- A. Moves in or out to focus image
- B. Magnifies image
- C. Reduces glare
- D. Holds the light-gathering lens
- E. Gathers light

## 2 Focusing a telescope

**Safety Tip: Never look at the Sun or a bright object through your telescope! You will cause damage to your eye.**

1. Pull the small tube all of the way out of your telescope and place a piece of masking tape lengthwise along the tube.
2. Write the letter “e” to measure 1 centimeter tall on a 3-by-5-inch card. Place the card at eye level on a wall in a large room (your classroom, the library, etc.).
3. Starting at the wall, lay a tape measure on the floor. Pull 10 meters of tape out from the wall. This will be your distance scale, 0-10, with zero at the wall.
4. Stand at the 10-meter mark and use your telescope to observe the letter on the card on the wall. Pull the small tube in or out until the letter comes sharply into focus. Record your observations in the table below. For your observations, describe the appearance of the image in terms of orientation and apparent size.
5. Draw a pencil line on the masking tape where the short tube enters the long tube. Write “10 m” (your distance from the card) next to the mark.
6. Repeat steps 4 and 5, moving closer to the wall by one meter for each trial. Continue to move 1 meter closer to the card, while repeating steps 4 and 5, until you cannot bring the letter into focus.
7. Use a ruler with millimeter markings to measure the length of the small tube, from your marks to the edge of the tube, as shown. Record your measurements in Table 1.



**Table 1: Focusing a telescope**

Distance from card (m)	Observations	Length of small tube (mm)
10		
9		
8		
7		
6		
5		
4		
3		
2		
1		

### 3 Stop and think

- a. In general, as you move closer to an object, how should you adjust the small tube?

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- b. When you view the letter “e” through your telescope, why does the image appear upside down? (HINT: Trace the light rays coming from the penny in the picture on the first page of the investigation.)

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- c. Make a graph of distance versus length of the small tube. Would you describe the relationship as direct or inverse? Explain your answer.

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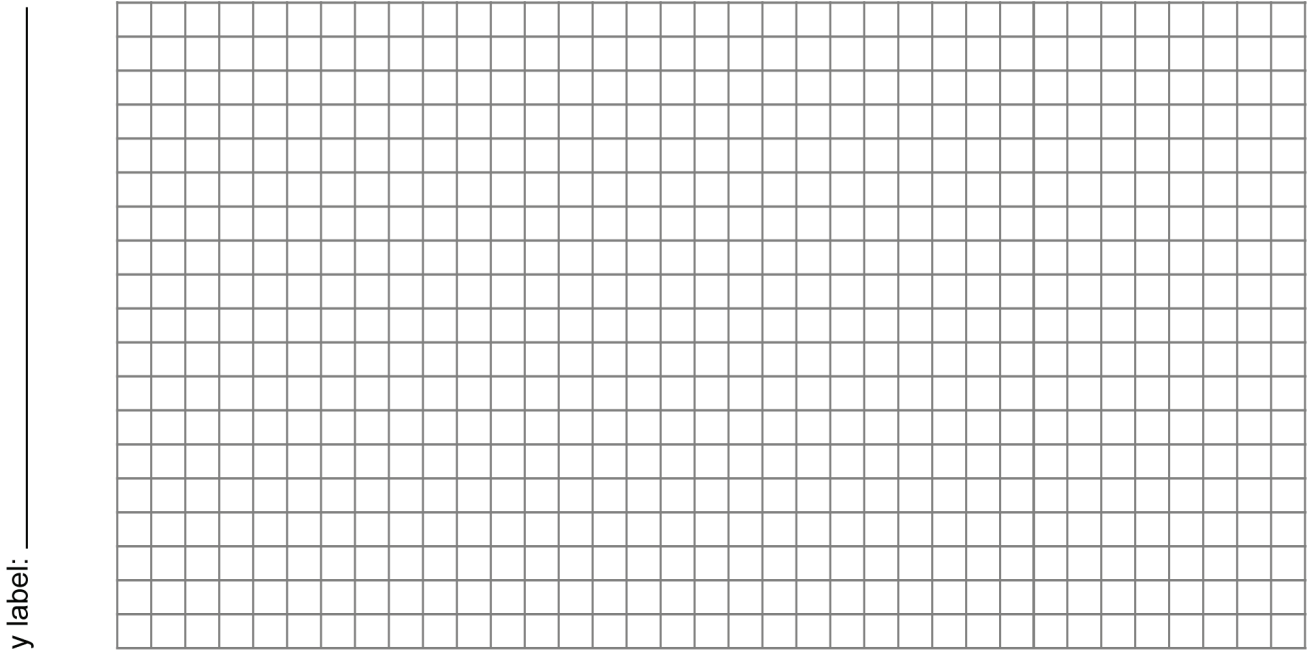


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Title: \_\_\_\_\_

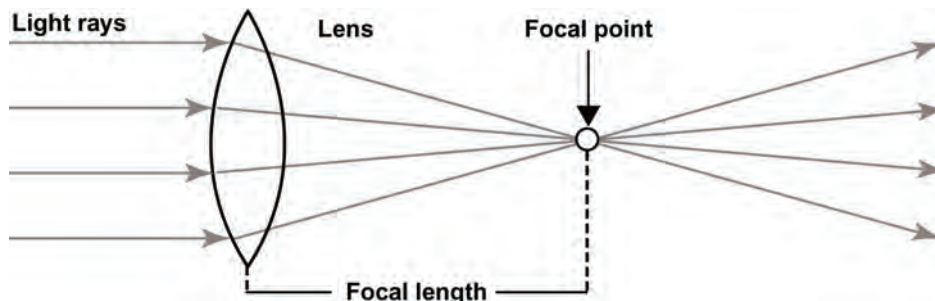


#### 4 Determining the magnification of a telescope

A telescope's magnification is a measure of the number of times the image being viewed is enlarged. A telescope magnification of 10x means the image of an object is magnified 10 times. The magnification of a telescope is the relationship between the objective lens and the eyepiece you are using. Since eyepieces in most telescopes can be interchanged, the magnification can vary. The magnification of a telescope is determined using the following equation:

$$\text{magnification} = \frac{\text{focal length of objective lens}}{\text{focal length of eyepiece}}$$

The **focal length** of a lens is the distance between the center of the lens and the focal point. The focal length of a lens is directly related to its diameter. The larger the diameter, the greater the focal length. Here is how the focal length of a lens is measured:





Popular focal lengths for eyepieces are 10 millimeters and 25 millimeters. Suppose your telescope has an objective lens with a focal length of 200 mm and an eyepiece with a focal length of 25 mm. What is the magnification of your telescope?

$$\text{magnification} = \frac{200 \text{ mm}}{25 \text{ mm}} = 8x$$

### 5 Thinking about what you observed

- a. If you wanted to increase the telescope's magnification in the problem above, which eyepiece would you choose—10 mm or 40 mm? Explain your answer and show your solution to the problem.

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- b. Calculate the magnification of the following telescopes:

Objective lens	Eyepiece	Magnification
1200 mm	10 mm	
1200 mm	25 mm	
800 mm	20 mm	

- c. A telescope with an 800 mm objective lens can gather more light than a telescope with a 200 mm objective lens. Does this mean that the 800 mm telescope has greater magnification than the 200 mm telescope? Explain your answer.

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- d. The focal lengths of two telescopes are shown below. Which telescope would have the greater magnification? Through which telescope would you expect to see a brighter image? Explain your answers.

**Telescope A:** 800 mm objective lens; 20 mm eyepiece

**Telescope B:** 200 mm objective lens; 5 mm eyepiece

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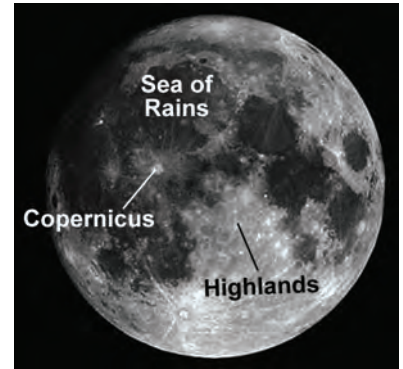


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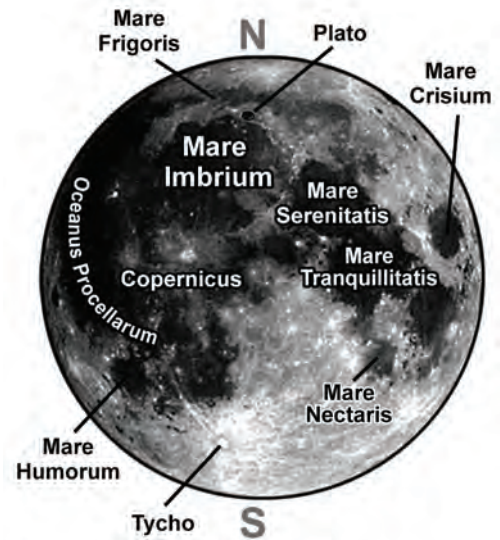
## 6 Observing the Moon

When you look at the Moon, you can see three main features of the lunar surface: craters, highlands, and maria. Craters are large, round pits that cover much of the Moon's surface. One of the Moon's largest craters, named for Copernicus, is hundreds of kilometers across.

Some areas of the Moon's surface appear bright, others dark. The brighter areas are called highlands because they are higher in elevation. The darker areas are called maria (a single area is called a mare) because early observers believed they were oceans. Maria are low, dry areas that were flooded with molten lava billions of years ago when the Moon was formed. Among the maria you can see through a telescope is a large one named Mare Imbrium, or Sea of Rains.



1. Find out on which evenings the Moon will be full, or at least 80 percent of its surface illuminated. This will be the best time for observing lunar features.
2. If you hold the telescope as steady as you can, what happens to the image of the Moon in your telescope over a few minutes, and why?
3. The diagram to the right shows the names of some of the craters, highlands, and maria you can observe. Study the diagram, then try to locate as many of the features as you can. Record all of the features you observe in a notebook.
4. As you observe the Moon, answer the questions below.



- a. How many craters can you see? Do they overlap? What do you believe this tells you about their age? Make sure you can locate Tycho, an 85-kilometer-wide crater on the lower part of the Moon that is the hub of a system of bright streaks.

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- b. How many maria (Latin for seas, remember?) can you see?

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**7 CHALLENGE! Observing Jupiter and its moons**

When it is visible, Jupiter is the third brightest object in the night sky—after the Moon and Venus. Though you will not be able to see any of Jupiter’s features through your telescope, you may be able to see four of its moons.

- a. Find out when Jupiter is visible in the night sky and the best time for viewing. Good resources include your local newspaper (the weather page) and the Internet.

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- b. Use a telescope to view Jupiter. How many moons do you see?

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- c. Why is Jupiter visible from Earth only during certain periods of time?
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# 19B Stars

## What are stars made of?

With the exception of the Sun, stars appear as small specks of light in the night sky. Astronomers use a technique called spectroscopy to analyze the light emitted by stars. Using spectroscopy, they can determine a star's temperature and the elements from which it is made. In this investigation, you will learn how to analyze light using spectroscopy. You will determine which elements are present in different light sources. You will then analyze the light emitted by the Sun.

### Materials

- Spectrometer
- Colored pencils

## 1 Using the spectrometer

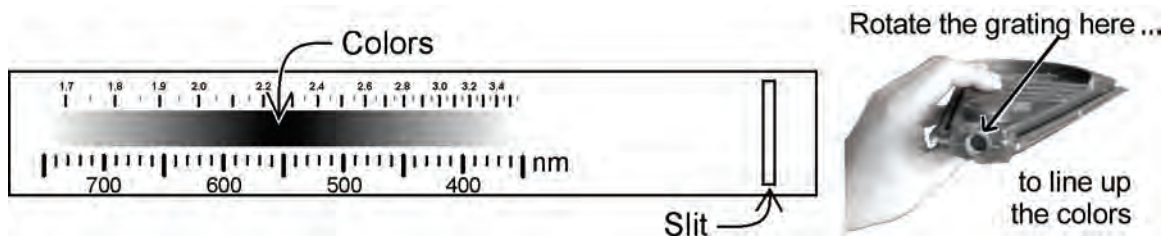
A spectrometer splits light into a spectrum of colors and displays the different colors of light along a scale. The scale measures the wavelengths of different colors of light in nanometers (nm).

**Safety Tip: Never look directly into any light source—especially the Sun!**

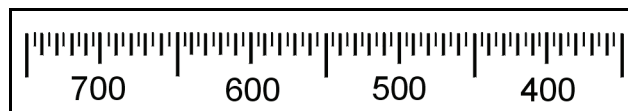


Hold the spectrometer so that the printed side is facing upward. In a well-lighted room, hold the spectrometer so that one eye is looking through the diffraction grating and the other eye is closed. You should see a scale, as illustrated below. The bottom scale measures wavelengths in nanometers. You should also notice colors at various places inside the spectrometer. This is caused by light entering the spectrometer from different sources.

Notice that the plastic disk that is attached to the diffraction grating can be turned. Looking into the spectrometer, rotate the disk until you see colors in a horizontal stripe to your left. The colors should appear between the two lines of numbers on the scales.



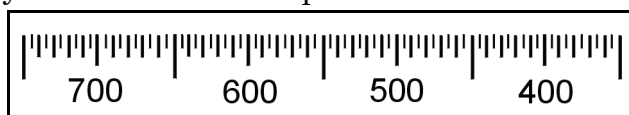
- While looking through the eyepiece, point the slit of the spectrometer directly at an incandescent bulb. Use colored pencils to show where the different colors of light appear on the spectrometer scale.



- b. Blue light has the highest energy and red light the lowest. Based on your observations with the spectrometer, what is the relationship between wavelength and amount of energy?

## 2 Using a spectrometer to identify elements in a fluorescent light

1. Use the spectrometer to examine a fluorescent light source (most likely the ones that illuminate your classroom). This time, you will see vertical lines (called spectral lines) of different colors instead of a smooth spectrum like you observed with the incandescent light.
2. You should see a green line at 546 nanometers on the scale. If the green line is not at 546 nanometers, ask your teacher to calibrate the spectrometer for you.
3. Use colored pencils to sketch the lines you observe. Be very precise in your sketch by placing the lines you see in the exact positions on the scale below.



4. Identify the wavelength of each spectral line, from left to right, then fill in Table 1.

**Table 1: Spectral lines produced by a fluorescent light**

Line number	Spectral line color	Spectral line wavelength (nm)
1		
2		
3		
4		

### What do the lines mean?

When elements are heated until they are hot enough to emit light (like those elements that make up stars), they produce characteristic spectral lines. Each element produces a pattern of spectral lines that is like a fingerprint. Shown to the right are some examples of the spectral lines produced by four different elements. Each line has a specific wavelength (these values are not shown in the diagram).

The light produced by a fluorescent source is created when electric current is passed through a gas inside of the tube. This gas, which is made of only one element, absorbs energy, and emits light.



Hydrogen



Helium



Neon



Mercury








- a. The light produced by the fluorescent tube you observed contains only one element. Compare the spectral lines you observed with the ones shown in the diagram above. Which element does it contain?
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- b. Fluorescent tubes have special instructions for disposal and must not end up in a landfill. Based on your spectral analysis of the gas inside the tube, why is this so?
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- 
- 
- 
- c. When astronomers use a spectrometer to analyze the light produced by stars, they observe the combined spectral lines of all of the elements present in the star. What specific information would an astronomer need to know in order to determine which elements are present in a star?
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### 3 Analyzing light from different sources

Identify five different light sources to observe with the spectrometer. Examples include gym lights, street lights, security lights, monitor screens, plant growing lights, and glow sticks. Write the types of light sources in the first column of Table 2. Follow the steps below for each light source.

1. Use the spectrometer to analyze the light emitted by the light source.
2. Use colored pencils to draw the position of each spectral line in column 2 of Table 2.
3. Record the wavelength, in nanometers, of each spectral line in the third column of Table 2.
4. Table 4 on the next page lists the values, in nanometers, of the spectral lines produced by various elements. Use these values to identify the elements found in each light source you observed and write them in the last column of Table 2.

**Table 2: Spectral lines produced by different light sources**

Light source	Spectrometer scale (nm)	Position of each vertical line (nm)	Elements present
			
			
			
			
			

a. If one light source displays more spectral lines than another, does that mean that it contains more elements? Explain your answer.

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b. Which light source contains the greatest variety of elements?

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c. Which light sources contain only one element?

#### **4 Analyzing the light from a star**

So far, the light sources you observed contain only a few elements. However, stars' atmospheres contain many elements and are much more complex.

1. Use the spectrometer to analyze the light of our closest star—the Sun. Do not point the spectrometer directly at the Sun. Instead, point it at reflected sunlight, off a cloud, for example, or a patch of blue sky.



- Record in Table 3 the color and value, in nanometers, of each spectral line you observe.
- Use Table 4, shown below, to identify the elements present in the Sun's atmosphere and record them in the third column of Table 3.

**Safety Tip: Do not point the spectrometer directly at the Sun. Point it only at reflected sunlight. NEVER look directly at the Sun!**

**Table 3: Analyzing light from the Sun**

Spectral line color	Spectral line wavelength (nm)	Element present

**Table 4: Spectral lines and elements present**

Spectral line (nm)	Element present	Spectral line (nm)	Element present
393	calcium	527	iron
397	calcium	546	mercury
405	mercury	577	mercury
434	hydrogen	579	mercury
436	mercury	589	sodium
486	hydrogen	590	sodium
517	magnesium	656	hydrogen
517	iron	687	oxygen

- a.** Explain why the Sun's light produces more spectral lines than the light sources you observed in Parts 2 and 3.

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- b.** Where do elements in the Sun's atmosphere come from? Explain your answer in detail.

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- c.** The Sun is a middle-aged star. If you could analyze the light from a much older star, what would you expect to see? Justify your answer using your knowledge of the star life cycle.

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