INTRODUCTION

About 4.6 billion years ago, our solar system evolved from a vast rotating cloud of cold gas and dust. The cloud separated into chunks of matter and collapsed inward. The Sun formed at the center of this matter as the interior started heating up. Near the Sun, rock and metal came together and eventually became the terrestrial (rocky) planets—Mercury, Venus, Earth, and Mars. The giant, gaseous planets—Jupiter, Saturn, Uranus, and Neptune—formed farther away from the Sun. Asteroids and frozen comets were formed from other loose material.

In this lesson, you will begin to investigate the solar system and its planets and asteroids. What do you already know about the solar system? How far apart are the planets? How do the sizes of other planets compare with Earth? You will examine these and other questions as you begin your journey through the solar system.

OBJECTIVES FOR THIS LESSON

- Brainstorm what you know and want to learn about the order and sizes of the planets and their distances from each other.
- Create a model of the solar system from a set of scaled items.
- Use scale models to explore the relative diameters of and distances between the nine planets and the Sun.
- Summarize and organize information about Mercury.
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Getting Started

1. Record in your science notebook what you already know about the order of, size of, and relative distances between the planets within the solar system. Share your ideas with the class.

2. Discuss with the class what “scale” means when used with maps. Then define the term “model” and give some examples. Why do you think it is important to build models to scale? Discuss with your class what a scale model of the solar system should look like.

Inquiry 11.1
Designing a Model Solar System

MATERIALS FOR INQUIRY 11.1

For you
1. copy of Student Sheet 11.1: Our Solar System Model

For your group
1. large resealable bag labeled “11.1” containing the following:
   2. rubber balls
   2. Ping-Pong balls
   2. plastic buttons
   2. marbles
   2. acrylic beads
   2. wood barrel beads
   2. fishing bobbers
   3. split peas
   3. pieces of round oat cereal
   1. strip of adding machine tape
   1. marker

PROCEDURE

1. Review with your teacher how to convert millimeters to centimeters.

2. Obtain one large resealable bag labeled “11.1.” Work with your group to select an object from the bag to represent each planet.

3. Label one end of the strip of adding machine tape “Sun.” Position the objects that you have selected along the tape to show the order of, relative sizes of, and relative distances between the planets.

4. Measure the diameter of each planetary model (in centimeters) and record each object’s name and diameter on Student Sheet 11.1: Our Solar System Model. Measure and record the distance (in centimeters) between each model planet and your “Sun.”

5. Draw a picture of your solar system model on Student Sheet 11.1. Label your drawing. Note any similarities in sizes of or distances between your model planets.
REFLECTING ON WHAT YOU’VE DONE

1. Share your group's solar system model with the class.

2. Answer the following questions in a class discussion. Answer them in your science notebook as well, if instructed to do so by your teacher.

   A. What was the largest planet in your model? What was the smallest planet?

   B. Do you observe any patterns in the sizes of the planets in your model? If so, what are they?

   C. Do you observe any patterns in the distances between your planets in your model? If so, what are they?

   D. Do you think the objects in your model are to scale in terms of size? Why or why not?

   E. Do you think the objects in your model are to scale in terms of distance? Why or why not?

3. Clean up by returning all your objects to the resealable bag. Save the adding machine tape for another class, if possible.

Inquiry 11.2
Using a Scale Factor

MATERIALS FOR INQUIRY 11.2

For you

1 copy of Student Sheet 11.2: Using a Scale Factor
1 calculator (optional)

PROCEDURE

1. Examine the illustration shown in Figure 11.1. How big would the model of a school bus 10 m long be if the scale factor that was used to make the model bus is 1 cm = 2 m?

   Figure 11.1  How many centimeters long would a model of a 10-m school bus be if every centimeter represents 2 m?

2. Set up your ratio as follows:

   \[ \frac{x}{10 \text{ m}} = \frac{1 \text{ cm}}{2 \text{ m}} \]

   \[ x \times 2 \text{ m} = 10 \text{ m} \times 1 \text{ cm} \]

   \[ x \times 2 \text{ m} = 10 \text{ m} \times \text{cm} \]

   \[ x = \frac{(10 \text{ m} \times \text{cm})}{2 \text{ m}} \]

   \[ x = 5 \text{ cm} \]
Divide the actual size of the bus by 2 m, and then multiply the answer by 1 cm. This will help you calculate the size of the model. That is, $10 \text{ m} \div 2 \text{ m} = 5 \times 1 \text{ cm} = 5 \text{ cm}$. The model bus would be 5 cm long.

3. Discuss with your teacher why the ratio “1 cm = 2 m” in Procedure Step 1 is considered a “scale factor.” How would you define “scale factor?” Record your working definition of this term in your notebook.

4. Calculate the scaled diameter (SD) of Earth with a scale factor (sf) of 1 cm = 10,000 km (or, 1:10,000). Hint: Divide the actual diameter (AD) of Earth (12,756 km) by 10,000 km—the scale factor—and then multiply your answer by 1 cm. Here is what the formula might look like:

Scaled Diameter (SD) : Actual Diameter (AD) = 1 cm : scale factor (sf)

\[
\frac{\text{Scaled Diameter (SD)}}{\text{Actual Diameter (AD)}} = \frac{1 \text{ cm}}{\text{scale factor (sf)}},
\]

\[
\text{SD} = \frac{1 \text{ cm}}{\text{sf}} \times \text{AD}
\]

or

\[
\text{SD} = \frac{\text{AD} \div \text{sf}}{\text{sf}} \times \text{cm}
\]

5. Review the actual diameters and distances of the planets listed in Table 1: Using a Scale Factor on Student Sheet 11.2. Calculate the approximate scaled distances and diameters for each planet by using a scale factor of 1 cm = 10,000 km. Record your calculations in the appropriate columns of Table 1 on Student Sheet 11.2. Show all your work.

REFLECTING ON WHAT YOU’VE DONE

1. Review your data on Student Sheet 11.2: Using a Scale Factor with the class.

2. Answer the following questions in your notebook, and then discuss them with your class:

A. How close was your model during Inquiry 11.1 to the scaled model calculated during Inquiry 11.2?

B. Does anything about your calculations on Student Sheet 11.2 surprise you? Explain.
Inquiry 11.3
Building a Scale Model of the Solar System

MATERIALS FOR INQUIRY 11.3

For you
1. copy of Student Sheet 11.3a: Calculating the Scale Factor
2. copy of Student Sheet 11.3b: Calculating Scaled Distance
3. copy of Student Sheet 10.1c: Planetary Chart

For your group
1. small plastic resealable bag labeled “11.3” and containing the following:
   - 2 small round beads, 0.2 cm
   - 2 peppercorns, 0.46 cm
   - 1 rubber ball, 5.5 cm
   - 1 fishing bobber, 4.6 cm
   - 2 acrylic beads, 1.7 cm
   - 1 straight pin with round head, 0.09 cm
2. metric ruler, 30 cm (12”)
3. metric measuring tape
4. set of 9 Planet Data Cards
5. calculator

PROCEDURE

1. Collect one resealable bag of items labeled “11.3.” These items are to scale with the actual diameter measurements of the planets.

2. Which object do you think represents each planet? Position the items so that they represent the size of the nine planets (do not consider distance at this point). Record the names of these objects in the third column of Table 1 on Student Sheet 11.3a: Calculating the Scale Factor.

3. Measure the diameter of each of your model planets by placing each object directly onto your ruler or measuring tape (or you can mathematically calculate its diameter from its circumference). Check your measurements against those in the Materials List. Record the diameter of each object in the fourth column of Table 1 on Student Sheet 11.3a.

4. Calculate the scale factor for each model planet. Remember to record your units. Use the example on Student Sheet 11.3a to guide you.

5. Calculate the average scale factor by adding all the scale factors together and dividing by 9. Remember to record your units. This average is the approximate scale factor for your entire model solar system.

6. Share your results with the class.

7. Using Student Sheet 11.3b and working with your group, calculate the scaled distance of each planet from the Sun. Refer to the actual distances of the planets from the Sun. Use the scale factor you calculated on Student Sheet 11.3a to determine how far from a model Sun to place each planet. This will help you to create an accurate scale solar system model for both size and distance. Use the example on Student Sheet 11.3b to help you. Note that each answer for scaled distance on Student Sheet 11.3b initially will be in centimeters. However, you will have to convert your answers to either meters or kilometers to make the measurements more meaningful.

8. If possible, go with the class to a long hall or gymnasium, or outdoors to an athletic field. Select one item in the area (for example, a wall or a goal post) to represent the Sun. Then, using your calculations, work with the class to measure the distances for each of the model planets as directed by your teacher. Label each planet with the appropriate planet data card. Don’t be surprised that Pluto may be more than a mile away!
8. If possible, go with the class to a long hall or gymnasium, or outdoors to an athletic field. Select one item in the area (for example, a wall or a goal post) to represent the Sun. Then, using your calculations, work with the class to measure the distances for each of the model planets as directed by your teacher. Label each planet with the appropriate planet data card. Don’t be surprised that Pluto may be more than a mile away!

**REFLECTING ON WHAT YOU’VE DONE**

1. Answer the following questions in your notebook, and then discuss them as a class:

   A. What observations and comparisons can you make about your model?

   B. How does Earth compare with other planets in size and distance from the Sun?

   C. How is your model different from the actual solar system?

   D. How is your model similar to the actual solar system?

   E. What is the relationship between the diameter of the planets and their positions from the Sun? What reasons do you have for your answer?

   F. Analyze Table 1 on Student Sheet 11.3b. How do the distances between the first four planets compare with the distances between the other planets? What reasons do you have for your answer?

   G. Think back to “Getting Started.” How is your final solar system model different from your earlier statements about what a model of the solar system looks like?

2. Obtain one set of Planet Data Cards for your group. Examine the planetary distances and determine what units are used to describe this value. What do you think AU means?

3. Use your calculator to determine how the AU for each planet was calculated. AU is the scale factor most often used when describing planetary distances.

4. Read “The Orrery: A Model of the Solar System” and think about how your observations of the solar system model can be applied to a real model.

5. Read “Mission: Mercury.” Add any information about Mercury to your working copy of Student Sheet 10.1c: Planetary Chart (and onto Student Sheet 10.1b: Planetary Brochure Outline if your Anchor Activity planet is Mercury).
The Orrery: A Model of the Solar System

When you build a model of a ship, a rocket, or another object, you usually want it to look as much like the original as possible. When Englishman George Graham built the first mechanical model of the solar system in 1700, he had the same goal. He wanted his model to look like the actual solar system. He duplicated the positions of the Sun and the planets and moons that were known at that time. With Graham’s model, people could see for the first time how Earth moved around the Sun. They could also follow the movements of Mercury, Venus, Mars, Jupiter, and Saturn.

Graham’s model became known as an “orrery.” It was named after Charles Boyce, the 4th Earl of Orrery, who commissioned such a model to be built. The orrery shown here was made in the 1780s. It belongs to the Smithsonian Institution in Washington, D.C. Is there an orrery at a science museum near you? □

SMITHSONIAN PHOTO BY ERIC LONG, © 1993, SMITHSONIAN INSTITUTION

The Astrarium: A Clock Without a Tock

This amazing clock was designed nearly 700 years ago by Giovanni de Dondi. The clock, or astrarium, works like this: One wheel turns once a day and moves another wheel, which makes one complete turn a year. The astrarium tracks the changing positions of the Earth, Moon, Sun, and the five other planets that were known at de Dondi designed the astrarium—Mercury, Venus, Mars, Jupiter, and Saturn. This complex astronomical tool even includes a calendar of all Roman Catholic feasts. De Dondi’s invention eventually was dismantled so that its brass could be reused. Luckily, de Dondi left detailed notes about how to construct the astrarium, which were used to make this reproduction.

SMITHSONIAN PHOTO BY ALFRED HARRELL, © 1992 SMITHSONIAN INSTITUTION
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SMITHSONIAN PHOTO BY ALFRED HARRELL, © 1992 SMITHSONIAN INSTITUTION
Mission: Mercury

Five thousand years ago, astronomers in the ancient civilization of Sumeria (located in present-day Iraq) identified Mercury as a planet. Because it is so close to the Sun, Mercury can only be seen along the horizon just before sunrise or just after sunset. When Mercury is directly overhead, the Sun’s light obscures any view of the planet.

The fact that Mercury is difficult to view didn’t stop scientists from trying to learn about it. At the turn of the 20th century, the astronomer Eugenious Antoniadi used a telescope to observe Mercury. He created maps of the planet that were used for nearly 50 years.

Scientists once thought that Mercury’s day was the same length as its year. But in 1965, scientists used Doppler radar observations to prove that Mercury rotates three times for every two times it orbits the Sun. Despite this new knowledge, scientists still had many questions about the innermost planet of our solar system. So, to learn more about Mercury, the Mariner 10 mission was launched from Kennedy Space Center on November 3, 1973.

The Mariner 10 Flight

Mariner 10 was a small spacecraft. Its body was only 1.39 meters by 0.457 meters—less than the width of most classroom desks! However, solar panels, antennae, and sunshades added to Mariner 10’s size. The spacecraft contained instruments to study the atmospheric, surface, and physical characteristics of Mercury. The solar panels and rocket engine helped Mariner 10 reach the planet.

Mariner 10 transmitted the first photographs of Mercury’s surface.
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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Mariner 10 did not fly directly to Mercury. After leaving Earth’s atmosphere, it flew by Venus and used that planet’s gravitational pull to bend its flight path toward Mercury. After almost five months in flight, Mariner 10 made its first flyby of Mercury. The term “flyby” refers to a method astronomers use to observe a planet. Instead of having a spacecraft orbit or land on a planet, a flyby spacecraft does just that—it “flies by” a planet, taking pictures of it and gathering other scientific data. After Mariner 10 completed its flyby of Mercury, it began orbiting the Sun. Using the last of its fuel, scientists were able to have Mariner 10 fly over Mercury two more times in September 1974 and March 1975. Since then, Mariner 10 has continued its orbit of the Sun, even though it is no longer operational.

NASA diagram of the Mariner 10 trajectory as outlined during mission planning in 1972. Follow the dashed line to trace the path of Mariner 10 from Earth to Mercury.
Mariner's Look at Mercury
During each flyby, Mariner 10 gathered images and data. Cameras on the spacecraft took more than 2500 images of Mercury. These images mapped almost half of Mercury's surface. Why only half? Because Mercury rotates so slowly that a single day on Mercury lasts longer than 58 Earth days! Because of the timing of the three flybys, the same side of the planet was always in the dark when Mariner was close enough to take photographs.

Half of Mercury's surface
The photos taken by the *Mariner 10* revealed a heavily cratered surface much like that of the Moon. Craters with bright “rays” can be seen scattered among dark plains. These rays may be material ejected from the craters during impact. Scientists believe that some of Mercury’s smooth plains were caused by lava flow. The cameras also took photos of a huge crater, Caloris Basin. This crater is 1,300 kilometers across and may have been caused by an asteroid impact. Scientists believe this impact also caused the formation of hills on the other side of the planet. Other photographs taken by the *Mariner 10* showed faults on the surface. Evidence suggests that pieces of Mercury’s crust have overlapped at these places.

The most surprising find of the *Mariner 10* mission was that Mercury has a magnetic field. Some scientists think the magnetic field indicates that the planet has an iron core that is partially molten. Others think that an ancient magnetic field may be frozen in the crust.

**Future Missions**

More missions to Mercury are planned, including sending an orbiter around Mercury. An orbiter is a spacecraft that studies a planet by orbiting it instead of just flying past the planet. By sending an orbiter around Mercury, scientists hope to make more detailed studies of this planet. They want to map the entire planet.

Another goal is to land equipment on the planet, such as a camera, a seismometer, and tools for studying Mercury’s soil. A spacecraft that lands on the planet is called a “lander.” In such a mission, scientists hope to gather data directly from the planet’s surface to answer numerous questions: What is the composition and structure of Mercury’s crust? Has it experienced volcanism? What is the nature of its polar caps? With future missions, perhaps we will have answers to these questions, and have a better understanding of this planet.
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Mercury: Quick Facts

<table>
<thead>
<tr>
<th>Diameter</th>
<th>4878 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Distance from the Sun</td>
<td>57,900,000 km</td>
</tr>
<tr>
<td>Mass</td>
<td>$3.3 \times 10^{23}$ kg</td>
</tr>
<tr>
<td>Surface gravity (Earth = 1)</td>
<td>0.38</td>
</tr>
<tr>
<td>Average temperature</td>
<td>179 °C</td>
</tr>
<tr>
<td>Length of sidereal day</td>
<td>58 Earth days</td>
</tr>
<tr>
<td>Length of year</td>
<td>88 Earth days</td>
</tr>
<tr>
<td>Number of moons</td>
<td>0</td>
</tr>
</tbody>
</table>

Did You Know?
- Mercury is barely larger than Earth's Moon. See the illustration "Relative Size" above, comparing Earth to Mercury.
- Mercury was named for the messenger of the gods because it moves so quickly across the sky. It races along in its orbit at a rate of 46.4 kilometers per second—faster than any other planet!