EXERCISE **18**

# Patterns in the Solar System

Although composed of many diverse objects, the solar system (Figure 18.1) exhibits various degrees of order and several regular patterns. To simplify the investigation of planetary sizes, masses, etc., the planets can be arranged into two distinct groups, with the members of each displaying similar attributes. This exercise examines the physical properties and motions of the planets with the goal of summarizing these characteristics in a few general, easily remembered statements.

## Objectives

After you have completed this exercise, you should be able to:

1. Describe the appearance of the solar system when it is viewed along the plane of the ecliptic.
2. Summarize the distances and spacing of the planets in the solar system.

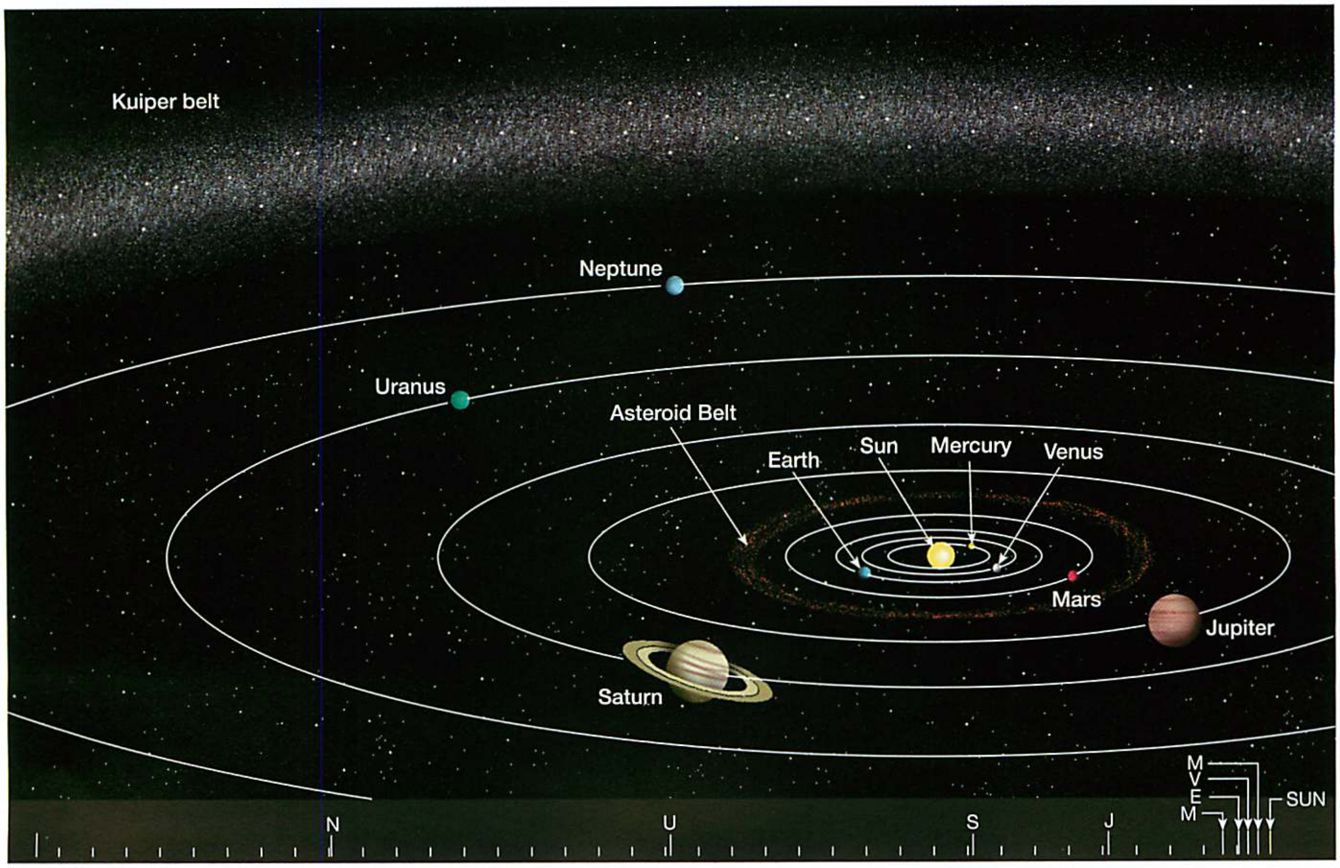


Figure 18.1 The solar system showing the orbits of the planets to scale. A different scale has been used for the sizes of the Sun and planets. Therefore, the diagram is not a true scale model representation of the solar system.

3. Summarize and compare the physical characteristics of the terrestrial and Jovian planets.
4. Describe the motions of the planets in the solar system.

## Materials

ruler
colored pencils
calculator

*Materials Supplied by Your Instructor*

4-meter length of adding machine paper
meterstick
light source (150-watt bulb)
black containers with covers and thermometers

## Terms

nebula
terrestrial planets
Jovian planets
dwarf planets
plane of the ecliptic
mass
density
weight
rotation
revolution
Kepler's laws
astronomical unit

## Introduction

The order that exists within the solar system is directly related to the laws of physics that governed its formation. Astronomers have determined that the Sun and planets originated approximately 4.6 billion years ago from an enormous cloud of dust and gas. As this **nebula** contracted, it began to rotate and flatten. Eventually the temperature and pressure in the center of the cloud was great enough to initiate nuclear fusion and form the Sun.

Near the center of the nebula, the planets Mercury, Venus, Earth, and Mars evolved under nearly the same conditions and consequently exhibit similar physical properties. Because these planets are rocky objects with solid surfaces, they are collectively called the **terrestrial (Earth-like) planets**.

The outer planets, Jupiter, Saturn, Uranus, and Neptune, being farther from the Sun than the terrestrial planets, formed under much colder conditions and are gaseous objects with central cores of ices and rock. Since the four planets are very similar, they are often grouped together and called the **Jovian (Jupiterlike) planets**.

The **dwarf planets**, which include, among other celestial objects, Pluto and the former asteroid Ceres, are not included with either the terrestrial or Jovian planets.

Table 18.1 illustrates many of the individual characteristics of the planets in the solar system.

1. Examine the data in Table 18.1, then
   a. Draw lines on the upper and lower parts of Table 18.1 that separate the terrestrial planets from the Jovian planets. Label the lines "Belt of Asteroids."

**Table 18.1 Planetary data.**

| Planet | Symbol | Mean Distance from Sun | | | Period of Revolution | Inclination of Orbit | Orbital Velocity | |
|---|---|---|---|---|---|---|---|---|
| | | AU | Millions of Miles | Millions of Kilometers | | | mi/s | km/s |
| Mercury | ☿ | 0.387 | 36 | 58 | $88^{d}$ | 7°00′ | 29.5 | 47.5 |
| Venus | ♀ | 0.723 | 67 | 108 | $224.7^{d}$ | 3°24′ | 21.8 | 35.0 |
| Earth | ⊕ | 1.000 | 93 | 150 | $365.25^{d}$ | 0°00′ | 18.5 | 29.8 |
| Mars | ♂ | 1.524 | 142 | 228 | $687^{d}$ | 1°51′ | 14.9 | 24.1 |
| Jupiter | ♃ | 5.203 | 483 | 778 | $11.86^{yr}$ | 1°18′ | 8.1 | 13.1 |
| Saturn | ♄ | 9.539 | 886 | 1427 | $29.46^{yr}$ | 2°29′ | 6.0 | 9.6 |
| Uranus | ⛢ | 19.180 | 1783 | 2870 | $84^{yr}$ | 0°46′ | 4.2 | 6.8 |
| Neptune | ♆ | 30.060 | 2794 | 4497 | $165^{yr}$ | 1°46′ | 3.3 | 5.3 |

| Planet | Period of Rotation | Diameter | | Relative Mass (Earth = 1) | Average Density (g/cm³) | Polar Flattening (%) | Mean Temperature (°C) | Number of Known Satellites |
|---|---|---|---|---|---|---|---|---|
| | | Miles | Kilometers | | | | | |
| Mercury | $59^{d}$ | 3015 | 4854 | 0.056 | 5.4 | 0.0 | 167 | 0 |
| Venus | $244^{d}$ | 7526 | 12,112 | 0.82 | 5.2 | 0.0 | 464 | 0 |
| Earth | $23^{h}56^{m}04^{s}$ | 7920 | 12,751 | 1.00 | 5.5 | 0.3 | 15 | 1 |
| Mars | $24^{h}37^{m}23^{s}$ | 4216 | 6788 | 0.108 | 3.9 | 0.5 | −65 | 2 |
| Jupiter | $9^{h}50^{m}$ | 88,700 | 143,000 | 317.87 | 1.3 | 6.7 | −110 | 63 |
| Saturn | $10^{h}14^{m}$ | 75,000 | 121,000 | 95.14 | 0.7 | 10.4 | −140 | 56 |
| Uranus | $17^{h}14^{m}$ | 29,000 | 47,000 | 14.56 | 1.2 | 2.3 | −195 | 27 |
| Neptune | $16^{h}03^{m}$ | 28,900 | 46,529 | 17.21 | 1.7 | 1.8 | −200 | 13 |

b. On both parts of the table write the word "terrestrial" next to Mercury, Venus, Earth, and Mars and the word "Jovian" next to Jupiter, Saturn, Uranus, and Neptune.

## The "Shape" of the Solar System

When the solar system is viewed from the side, the orbits of the planets all lie in nearly the same plane, called the **plane of the ecliptic** (Figure 18.1). The column labeled "Inclination of Orbit" in Table 18.1 lists how many degrees the orbit of each planet is inclined from the plane. Answer questions 2–4 by referring to Table 18.1.

2. Other than Mercury, whose orbit is inclined (4, 7, 10) degrees, the orbits of the remaining planets are all within (4, 7, 10) degrees of the plane of the ecliptic. Circle your answers.
3. The orbit of the dwarf planet Pluto is inclined 17° to the plane. When compared to the eight planets, Pluto's orbit is:

______________________________

4. Considering the nebular origin of the solar system, suggest a reason why the orbits of the planets are nearly all in the same plane.

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## Distance and Spacing of the Planets

An examination of any scale-model solar system reveals that the distances from the Sun and the spacing between the planets appear to follow a regular pattern. Although many ancient astronomers were concerned with planetary distances and spacing, it was not until the mid-1700s that astronomers found a simple mathematical relation that described the arrangement of the planets known at the time.

### A Scale Model of Planetary Distances

Perhaps the best way to examine distance and spacing of the planets in the solar system is to use a scale model.

5. Prepare a distance scale model of the solar system according to the following steps.

**Step 1:** Obtain a 4-meter length of adding machine paper and a meterstick from your instructor.

**Step 2:** Draw an "X" about 10 centimeters from one end of the adding machine paper and label it "Sun."

**Step 3:** Using the mean distances of the planets from the Sun in miles presented in Table 18.1 and the following scale, draw a small circle for each planet at its proper scale mile distance from the Sun. Use a different colored pencil for the terrestrial and Jovian planets and write the name of the planet next to its position.

**SCALE**

1 millimeter = 1 million miles

1 centimeter = 10 million miles

1 meter = 1,000 million miles

**Step 4:** Write the word "asteroids" 258 million scale miles from the Sun.

Answer questions 6–9 using the distance scale model you constructed in question 5.

6. What feature of the solar system separates the terrestrial planets from the Jovian planets?

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7. Observe the scale model diagram and summarize the spacing for each of the two groups of planets.

Spacing of the terrestrial planets: ____________

______________________________

Spacing of the Jovian planets: ____________

______________________________

8. Write a brief statement that describes the spacing of the planets in the solar system.

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9. Which planet(s) vary the most from the general pattern of spacing?

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## Comparing the Terrestrial and Jovian Planets

The physical characteristics such as diameter, density, and mass of the terrestrial planets are very similar and can be summarized in a few statements. Likewise, the characteristics exhibited by the Jovian planets as a group can also be generalized.

To gain an understanding of the similarities of the planets within each of the two groups and the contrasts between the two groups, complete the following sections using the planetary data presented in Table 18.1.

## Size of the Planets

The similarities in the diameters of the planets within each of the two groups and the contrast between the groups are perhaps the most obvious patterns in the solar system. The diameter of each planet is given in both miles and kilometers in Table 18.1.

**10.** To visually compare the relative sizes of the planets and Sun, complete the following steps using the unmarked side of your 4-meter length of adding machine paper.

**Step 1:** Determine the radius of each planet in kilometers by dividing its diameter (in kilometers) by 2. List your answers in the "Radius" column of Table 18.2.

**Step 2:** Use a scale of 1 cm = 2,000 km. Determine the scale model radius of each planet and list your answer in the "Scale Model Radius" column of Table 18.2.

**Step 3:** Draw an "X" about 10 cm from one end of the adding machine paper and label it "Starting point."

**Step 4:** Using the scale model radius in Table 18.2, begin at the starting point and mark the radius of each planet with a line on the paper. Use a different colored pencil for the terrestrial and Jovian planets. Label each line with the planet's name.

**Step 5:** The diameter of the Sun is approximately 1,350,000 kilometers. Using the same scale as you used for the planets (1 cm = 2000 km), determine the scale model radius of the Sun. Mark the Sun's radius on the adding machine paper using a different colored pencil from the two planet groups. Label the line "Sun."

**Table 18.2 Planetary Radii with Scale Model Equivalents**

| Planet | Radius (in kilometers) | Scale Model Radius |
|---|---|---|
| Mercury | ____________ | ____________ cm |
| Venus | ____________ | ____________ cm |
| Earth | ____________ | ____________ cm |
| Mars | ____________ | ____________ cm |
| Jupiter | ____________ | ____________ cm |
| Saturn | ____________ | ____________ cm |
| Uranus | ____________ | ____________ cm |
| Neptune | ____________ | ____________ cm |

Answer questions 11–17 using both Table 18.1 and the scale model radius diagram you constructed in question 10.

**11.** Which is the largest of the terrestrial planets and what is its diameter?

____________, ____________ miles

**12.** Which is the smallest Jovian planet and what is its diameter?

____________, ____________ miles

**13.** Complete the following statement.

The smallest Jovian planet, ____________, is ____________ times larger than the largest terrestrial planet.

**14.** Summarize the sizes of the planets within each group.

The diameters of the terrestrial planets: ________

________________________________

The diameters of the Jovian planets: ________

________________________________

**15.** Write a general statement that compares the sizes of the terrestrial planets to those of the Jovian planets.

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________________________________

**16.** Complete the following statement.

The Sun is ________ times larger than Earth and ________ times larger than Jupiter.

**17.** The diameter of the dwarf planet Pluto is approximately 1,500 miles, which is about (one-third, one-half, twice) the diameter of the smallest planet. Circle your answer.

## Mass and Density of the Planets

**Mass** is a measure of the quantity of matter an object contains. In Table 18.1 the masses of the planets are given in relation to the mass of Earth. For example, the mass of Mercury is given as 0.056, which means that it consists of only a small fraction of the quantity of matter that Earth contains. On the other hand, the Jovian planets all contain several times more matter than Earth.

**Density** is the mass per unit volume of a substance. In Table 18.1 the average densities of the planets are expressed in grams per cubic centimeter ($g/cm^3$). As a reference, the density of water is approximately one gram per cubic centimeter.

Using the relative masses of the planets given in Table 18.1, answer questions 18–22.

18. Complete the following statements:

a. The planet ______________ is the most massive planet in the solar system. It is _________ times more massive than Earth.

b. The least massive planet is ______________, which contains only ________ as much mass as Earth.

The gravitational attraction of a planet is directly related to its mass.

19. Which planet exerts the greatest, and which the least, pull of gravity? Explain your answer.

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_______________________________________________

Your **weight** is a function of the gravitational attraction of an object on your mass.

20. The surface gravities of Mars and Jupiter are respectively about 0.4 and 2.5 that of Earth. What would be your approximate weight on each of these planets?

_______________________________________________

21. Which of the two groups of planets would have the greatest ability to hold large quantities of gas as part of their compositions? Explain your answer.

_______________________________________________

_______________________________________________

22. Write a general statement comparing the masses and gravitational attractions of the terrestrial planets to those of the Jovian planets.

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_______________________________________________

## Diameter versus Density

To visually compare the diameters and densities of the planets, use the data in Table 18.1 to complete the diameter versus density graph, Figure 18.2, according to the procedure in question 23.

23. Plot a point on the diameter verses density graph, Figure 18.2, for each planet where its diameter intersects its density. Label each point with the planet's name. Use a different colored pencil for the terrestrial and Jovian planets.

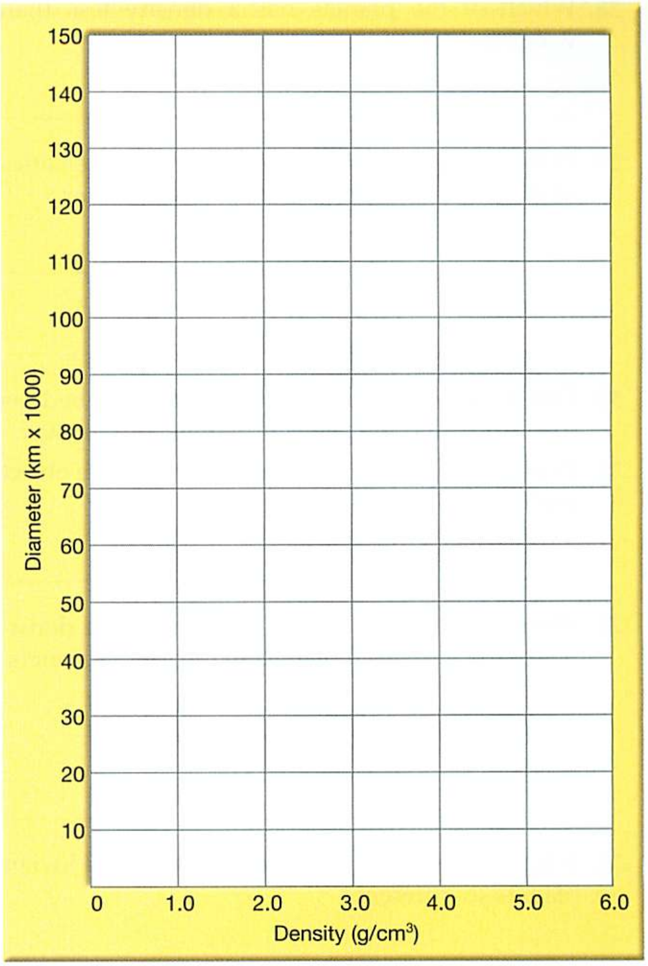


**Figure 18.2** Diameter verses density graph.

Answer questions 24–34 using Table 18.1 and the diameter verses density graph you constructed in question 23.

24. What general relation exists between a planet's size and its density?

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25. Consider the fact that the densities of the two rocks that form the majority of Earth's surface, the igneous rocks granite and basalt, are each about 3.0 $g/cm^3$. Therefore, the average density of the terrestrial planets is (greater, less than) the density of Earth's surface. Circle your answer.

26. The term (rocky, gaseous) best describes the terrestrial planets. Circle your answer.

27. The average density of Earth is about 5.5 $g/cm^3$. Considering that the densities of the surface rocks are much less than the average, what does this suggest about the density of Earth's interior?

_______________________________________________

28. Which of the planets has a density less than water and therefore would "float"?

29. Write a brief statement comparing the densities of the Jovian planets to the density of water.

30. The Jovian planets can be best described as (rocky, ice, and gas) worlds. Circle your answer.

31. Explain why Jupiter can be such a massive object and yet have such a low density.

32. Write a general statement comparing the densities of the terrestrial planets to the Jovian planets.

33. Why are the densities of the terrestrial and Jovian planets so different?

34. The mass of Pluto, about 0.002 that of Earth's, is most like the masses of the (terrestrial, Jovian) planets, while its density of approximately 2.0 $gm/cm^3$ is similar to the (terrestrial, Jovian) planets. This suggests that this dwarf planet is made of (solid rock, a rock and ice mixture, all gas). Circle the correct responses.

## Number of Moons of the Planets

The column labeled "Number of Known Satellites" in Table 18.1 indicates the number of known moons orbiting each planet.

35. Write a brief statement comparing the number of known moons of the terrestrial planets to the number orbiting the Jovian planets.

36. What is the general relation between the number of moons a planet has compared to its mass? Suggest a reason for the relation.

## Rotation and Revolution of the Planets

**Rotation** is the turning of a planet about its axis that is responsible for day and night. When the solar system is viewed from above the Northern Hemisphere of Earth, the planets, with the exception of Venus, rotate in a counterclockwise direction. Venus exhibits a very slow clockwise rotation. The time that it takes for a planet to complete one 360° rotation on its axis is called the *period of rotation*. The units used to measure a planet's period of rotation are Earth hours and days.

**Revolution** is the motion of a planet around the Sun. The time that it takes a planet to complete one revolution about the Sun is the length of its year, called the *period of revolution*. The units used to measure a planet's period of revolution are Earth days and years. Without exception, the direction of revolution of the planets is counterclockwise around the Sun when the solar system is viewed from above the Northern Hemisphere of Earth.

Use the planetary data in Table 18.1 to answer questions 37–46.

37. If you could live on Venus or Jupiter, approximately how long would you have to wait between sunrises?

On Venus a sunrise would occur every ________ days.

On Jupiter a sunrise would occur every _______ hours.

38. Write a statement comparing the periods of rotation of the terrestrial planets to those of the Jovian planets.

The giant planet Jupiter rotates once on its axis approximately every 10 hours. If an object were on the equator of the planet and rotating with it, it would travel approximately 280,000 miles (the equatorial circumference or distance around the equator) in about 10 hours.

39. Calculate the equatorial rotational velocity of Jupiter using the following formula.

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}} = \frac{\_\_\_\_\_\_\_\_\_\_\ \text{mi}}{\text{hr}}$$
$$= \_\_\_\_\_\_\_\_\_\_\ \text{mi/hr}$$

40. The equatorial circumference of Earth is about 24,000 miles. What is the approximate equatorial rotational velocity of Earth?

_______________ miles/hour

41. How many times faster is Jupiter's equatorial rotational velocity than Earth's?

________ times faster

42. Compare the planets' periods of rotation to their periods of revolution and then complete the following statement by circling the correct responses.

The terrestrial planets all have (long, short) days and (long, short) years, while the Jovian planets all have (long, short) days and (short, long) years.

43. In one Earth year, how many revolutions will the planet Mercury complete and what fraction of a revolution will Neptune accomplish?

Mercury: ________ revolutions in one Earth year

Neptune: ________ of a revolution in one Earth year

44. On Venus, how many days (sunrises) would there be in each of its years?

________ day(s) per year

45. How many days (rotations) will Mercury complete in one of its years?

Mercury: ________ Mercury days in one Mercury year

46. Explain the relation between a planet's period of rotation and period of revolution that would cause one side of a planet to face the Sun throughout its year.

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In the early 1600s Johannes Kepler set forth three laws of planetary motion. According to Kepler's third law, the period of revolution of a planet, measured in Earth years, is related to its distance from the Sun in astronomical units (one **astronomical unit (AU)** is defined as the average distance from the Sun to Earth—93 million miles or 150 million kilometers). The law states that a planet's orbital period squared is equal to its mean solar distance cubed ($p^2 = d^3$).

47. Applying Kepler's third law, what would be the period of revolution of a hypothetical planet that is 4 AUs from the Sun? Show your calculation in the following space.

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______________________________

______________________________

## Terrestrial Planet Temperatures

The temperature of an object is related to the intensity of the heat source, its distance from the source, and the nature of the material it is composed of. To better understand how these variables influence the temperatures of the terrestrial planets, observe the equipment in the laboratory (Figure 18.3) and then complete the following steps. Answer questions 48–51 after you complete your investigation.

**Step 1:** Working in groups of four or more, obtain four *identical* light (heat) sources and four *identical* black containers with covers and thermometers.

**Step 2:** Conduct four experiments simultaneously, one by each member of the group. Do one experiment with the covered can and thermometer 15 cm from the light source, another with the can 30 cm from the light source, the third 45 cm, and the fourth 60 cm.

**Step 3:** Note the starting temperature for each container on Table 18.3; the temperatures should all be the same.

**Step 4:** For each of the four setups, turn on the light and record the temperature of the container exactly 10 minutes later. Record the temperatures in Table 18.3.

**Step 5:** Using the temperature scale on the left axis of the graph, plot the temperatures from Table

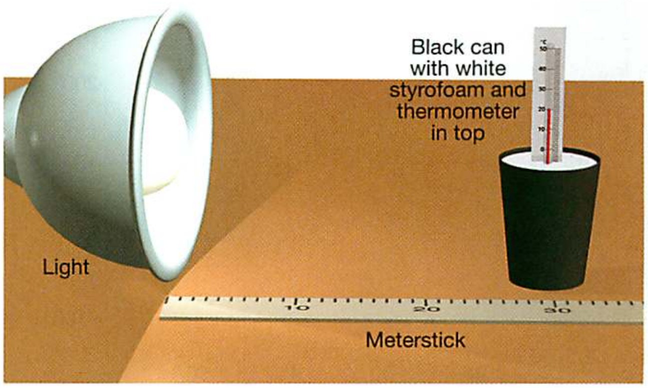


**Figure 18.3** Terrestrial planet temperatures lab-equipment setup.

**Table 18.3 Temperature Data**

| Distance from Light Source (cm) | Starting Temperature (°C) | 10-minute Temperature |
|---|---|---|
| 15 | | |
| 30 | | |
| 45 | | |
| 60 | | |

18.3 on the graph in Figure 18.4. Connect the points and label the graph "temperature change with distance."

**Step 6:** In Table 18.1, notice the mean temperatures for the planets. Plot the mean temperatures of the terrestrial planets at their proper locations on the graph, Figure 18.4. Assume a scale of 40 cm equals 1 AU and use the temperature scale on the right axis of the graph. Label each point with the planet's name. Connect the points and label the graph "mean terrestrial planet temperatures."

**48.** The "temperature change with distance" graph represents how you would expect that, everything else being equal, the temperature of a planet would be related to its distance from the Sun.

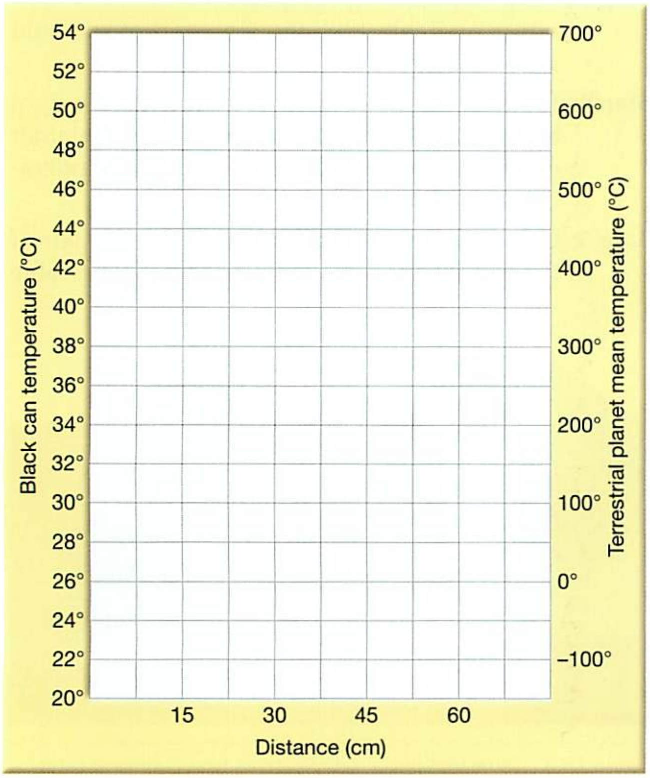


**Figure 18.4** Terrestrial planet temperatures graph.

In the following space, write a brief description of the "temperature change with distance" graph.

**49.** The "mean terrestrial planet temperatures" graph represents the real mean temperatures of the planets. Compare this graph to the theoretical "temperature change with distance graph." How are the graphs similar? How are they different?

**50.** Write a brief statement suggesting the reason(s) for the difference(s) between the two graphs you noted in question 49.

**51.** Complete your investigation by writing a statement describing the mean temperatures of the terrestrial planets and the variables that determine those temperatures.

## The Solar System on the Internet

Continue your analyses of the topics presented in this exercise by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

# Patterns in the Solar System

Date Due: ____________________

Name: ____________________

Date: ____________________

Class: ____________________

After you have finished Exercise 18, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. On Figure 18.5, prepare a sketch illustrating the planets Mercury, Venus, Earth, and Mars at their approximate distance from the Sun. View the solar system from above the Northern Hemisphere of Earth. Draw arrows around each planet to illustrate its direction of rotation. Also, draw an arrow in the orbit of each planet that shows the direction of revolution.
2. Briefly describe the spacing of the planets in the solar system.

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3. Define the following terms:

Terrestrial planets: ____________________

____________________

Jovian planets: ____________________

____________________

Plane of the ecliptic: ____________________

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Rotation: ____________________

____________________

Mass: ____________________

____________________

Astronomical unit: ____________________

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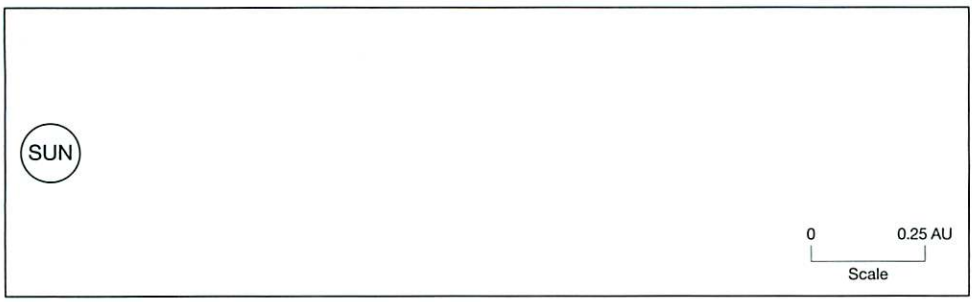


**Figure 18.5** Spacing and motion of the terrestrial planets.

4. Referring to the nebular origin of the solar system, describe and explain the direction of revolution of the planets.

5. Write a brief statement for each of the following characteristics that compares the terrestrial to the Jovian planets.

Diameter:

Density:

Period of rotation:

Number of moons:

Mass:

6. If you knew the distance of a planet from the Sun, explain how you would calculate its period of revolution.

7. How does a planet's distance from the Sun affect the solar radiation the planet receives? Why?

8. How are the mean temperatures of the terrestrial planets related to the solar radiation they intercept? What is the explanation for any discrepancy?

9. Considering what you have learned about general patterns in the solar system, after reexamining the characteristics of Pluto, discuss why this former planet was reclassified as a dwarf planet in 2006.