Unit 1: PLANETS AND STARS

Unit 1 is a descriptive introduction to our Solar System and the properties of the stars that lie beyond. Chapter 1, “The Solar System and Beyond,” will help students develop a feel for the sizes of objects within the Solar System as well as the distances between them, and distances between the Solar System and stars within our galaxy. Chapter 2, “The Nature of Stars,” discusses the stars' properties that are of primary importance to astronomers. These properties include size, brightness, and temperature, as well as their interrelationships. The knowledge and methods presented in this unit are the first steps on the road to becoming knowledgeable about astronomy, and perhaps to becoming an amateur astronomer!

CONTENTS FOR UNIT 1

Relationship to National Science Standards and Benchmarks

In Unit 1 we develop the unifying theme of "systems" by treating the Solar System as an organization of planetary bodies around a central star. Here we use a model as a method of understanding a system too large for visual observation. We show how several models can be used to represent the same thing, and that the scale of the models will determine their usefulness. The *Earth and Space Science Content Standard* states that by the end of eighth grade, students should develop an understanding of the Earth and Sun as an organized system, and be able to construct models that explain the physical relationships among the objects within the system. By the end of the twelfth grade, students should have acquired the ability to use observational data to continue inquiry into space science, even when things such as large distances are not directly observable. Students should also begin exposure to mathematics as a precise language used to describe objects, compare numbers of different sizes by expressing them as powers of 10, estimate sizes and distances, label numbers with appropriate units, and have the ability to convert units. This unit combines simple observations, basic knowledge, ideas, and open-ended questions to establish the basics of scientific inquiry. Especially in astronomy, students need to understand "how we know what we know." They should gain the confidence to use mathematical models to determine information. Eighth graders should know that light from the Sun (or any star) is made up of a mixture of different colors. All students should know that stars differ from each other in size and temperature, and that they behave according to well-defined physical principles.

Chapter 1: The Solar System and Beyond

Summary

Chapter 1 introduces the nature, size, and scale of the Solar System and its place in the Milky Way Galaxy, and includes some activities for expressing and visualizing these sizes and scales. This chapter is an excellent introduction to the *Hands-On Astrophysics* curriculum. It can also stand alone as an interesting mathematical approach to scales and ratios, fractions, powers of ten and scientific notation, exponents and estimation, or as a discussion of the purpose for the development and use of models to explain large- or small-scale phenomena.

Terminology

asteroid belt	meteorites	minor planets	planetoid
asteroids	meteoroids meteors	Oort Cloud	satellite/moon
astronomical unit (AU)	meteor showers	Perseid	Solar System
comets	Milky Way	planet	star
Kuiper belt		planetary system	

Common Misconceptions About the Solar System

1. *The actual difference in size for Solar System objects is small.*
2. *The orbits of the planets are equally spaced.*
3. *The spacing between planets is not much larger than the diameters of the planets themselves.*

SUGGESTIONS FOR THE POSTER PAGES, INVESTIGATIONS, AND ACTIVITIES

NOTE: All numeric values in the student pages use the metric system, which is the universal standard for precise measurement. All scientific measurements use the metric system, making it easy to repeat measurements anywhere and anytime. The United States officially recognizes the metric system and science and industry use it extensively. It is a much simpler system of measurements than the English system, but there is a great deal of hesitancy here to completely convert to metrics. Resistance to change, and probably even more important, the far-reaching economic implications of instituting the conversion, have slowed the inevitable. Sometime in the future we will have to change. This unit does not start with a tutorial on the metric system. It is introduced, throughout the curriculum, only on a need-to-know-and-use basis. This should help the students assimilate the metric system more easily. For your information, the English equivalents of the metric value are given in parentheses. You can choose how to share this information with your students. Familiarity with a system means having an intuitive feel for what the numbers represent, and they may need to know the corresponding values in the English system until they become familiar with the metric equivalents. The students should become more comfortable with the system after encountering it in this chapter and those that follow.

Poster Page: Who Is More Important? (Kepler and Brahe)

Johannes Kepler and Tycho Brahe are interesting personalities. The contrast in traits between the wealthy, noble, arrogant Brahe and the independent, withdrawn, and poverty-stricken Kepler resulted in a strained and tension-filled relationship between them. Research into their different and colorful lives will provide excellent material for term papers, book reports, and exploration of two totally different contributions to the scientific process. The backdrop of the 30 Years' War and the upheavals and religious persecution of the early 1600s will place the work of these two astronomers into a historical context. Students will be surprised to hear that the Roman Empire's line of emperors was still being maintained in exile by its descendants a thousand years after the fall of the Empire. Superstitions, alchemy, and beliefs in astrology held sway over the population. Astrologers were powerful. The interrelationship of astronomy and astrology is a subject within itself—indeed, many astronomers spent most of their time writing horoscopes to support themselves. Another aspect of historical context is the plague, rampant throughout this time and playing a significant role in the life of Kepler and others. Tycho's metal nose is always intriguing to students (particularly as it involves dueling)—how did one manufacture different metallic noses and attach them in the early 1600s? What was the state of their metallurgy? Tycho's grave was exhumed to see if the story about the nose could be verified. Is this a good reason to dig up a grave? What procedures have to be followed for exhumation? Students can explore the origin of science fiction; for an interesting avenue of discussion they could research how Kepler came to write his science fiction story "*Somnium,*" about a trip to the Moon. Several astronomers throughout history have also written science fiction. Another rich topic is the role nations and governments play in supporting, controlling, or withholding support of scientific and scholarly research and freedom of thought.

Investigation 1.1a: Estimating Sizes and Distances

Give each group of students a box with an assorted collection of objects. You may decide to project the following data table (Table 1.1) on an overhead. Ask the students to identify the object in their box that corresponds to the Sun. They can then select the objects which represent the planets by using the data in Table 1.1.

TABLE 1.1		
OBJECT	**EQUATORIAL RADIUS**	
	(km)	**(miles)**
SUN	696,000	431,520
MERCURY	2,440	1,513
VENUS	6,052	3,752
EARTH	6,378	3,954
MARS	3,397	2,106
JUPITER	71,492	44,325
SATURN	60,268	37,366
URANUS	25,559	15,846
NEPTUNE	24,764	15,354
PLUTO	1,151	714

Note: By convention, the *radius*, not the *diameter*, of a planet is usually listed in tables because it is used more frequently in mathematical relationships.

For example, the volume of a sphere ($V = 4/3\pi r^3$). Remind your students that they will need to double the radius to calculate the diameter.

Not all groups have to be given the same set of objects. More than the necessary amount of objects can be included to increase the difficulty of the sorting exercise. Another variation is to have the students find objects in their environment which correspond to the sizes of the planets after showing them a volley ball or cantaloupe to represent the Sun. You may elect to glue the objects representing planets onto cards, and insert the pins through pieces of cardboard so they are easier for students to handle.

This activity can be extended into a distance scale as well. Have the students discuss where to place the planets from the Sun using the same scale ratio used for the sizing of the planets. It is surprising that only Mercury, or maybe Venus depending on the size of the room, will fit inside the classroom. You will have to go outdoors, and have already selected a site approximately the length of 10 and a half football fields — ~950 meters (~1050 yards).

Estimation is a powerful skill, and even though this is not a core activity, choosing either this activity and/or one of the following activities is strongly suggested, as they are highly visual and directly address misconceptions involving size and distance.

Some suggested collections of objects:	**The distances are as follows:**
Sun: volleyball, cantaloupe; 20.5 cm (8.0 inches)	
Mercury: pinhead; .07 cm (.03 inches)	Mercury: 9.6 m (22.8 feet)
Venus: peppercorn; .20 cm (.08 inches)	Venus: 16.7 m (39.8 feet)
Earth: peppercorn; .20 cm (.08 inches)	Earth: 23.9 m (56.9 feet)
Mars: pinhead; .07 cm (.03 inches)	Mars: 35.8 m (85.2 feet)
Jupiter: chestnut; 2.30 cm (.90 inches)	Jupiter: 119.5 m (284.5 feet)
Saturn: hazelnut, acorn; 1.79 cm (.70 inches)	Saturn: 227.0 m (540.5 feet)
Uranus: peanut, coffee bean; .77 cm (.30 inches)	Uranus: 454.1 m (1081.2 feet)
Neptune: peanut, coffee bean; .77 cm (.30 inches)	Neptune: 717.0 m (1707.2 feet)
Pluto: pinhead; less than .07 cm (.03 inches)	Pluto: 956 m (2276.2 feet)

Investigation 1.1b: Sizing the Earth-Moon System

Students have misconceptions regarding the Earth-Moon system, since most illustrations are not accurate representations. Even though the Moon is the second-largest satellite in our Solar System, it appears relatively small next to the Earth. The Moon has one quarter of the Earth's diameter and approximately one-fiftieth of its volume. (From this, students tend to acquire the misconception that the Moon is one-quarter the *size* of the Sun.) In addition, the Moon's distance of thirty Earth diameters is visually impressive and usually quite a surprise to students, even if they "know the numbers" representing these distances.

Draw a 40-cm (16-inch) diameter circle on the board and label it Earth. Have the students predict the size of the Moon relative to this Earth circle, and have some of them draw their Moon circles on the board. Ask them to estimate how many Moons would fit into the Earth. After predictions have been discussed, explain that the true diameter of the Moon is about one-quarter of the diameter of the Earth. Therefore a 40-cm (16-inch) diameter Earth has a 10-cm (4-inch) diameter Moon. The following can either be done by groups of students or as a demonstration. Using a large piece of modeling clay, make 51 equal-sized balls of clay. Play-Doh™ can also be used; three cans with 17 balls made from each can will produce 51 balls.

Ask the students how many of the balls should be joined together to form the Earth and how many should be joined to form the Moon. Then take 50 of the balls and roll them into a single large ball. The large ball is a model of Earth and the single remaining ball is a model of the Moon. Ask students to comment on the relative sizes of the Earth and Moon. Even though they know that the diameter of the Earth is four times the diameter of the Moon, the difference in volume is usually a surprise! Explain that this is a properly-sized scale model of the Earth-Moon system and that fifty Moons are required to fill the same volume as the Earth.

Now ask the students to estimate the distance between the Earth model and the Moon model by indicating where the Moon should be placed relative to the Earth. After several estimates have been recorded, take a long piece of string and with one end measure the diameter of the Earth. Then fold the string back on itself repeatedly until the length is equal to thirty times the diameter of the Earth (3.81 m or 3.02 yards). Stretch out the string and then place the Moon at the appropriate distance. This is now an accurately scaled model of both size and distance for the Earth-Moon system.

This model should be left on display to reinforce the sense of scale. To help illustrate the scale, ask students how far from the Earth the Space Shuttle orbits. The shuttle orbits at a maximum altitude of 480 km (300 miles). If the Earth models that were created are approximately 12.5 cm (5 inches) in diameter—as they will be if the students used the Play-Doh™—insert a toothpick into the Earth model until just about 3½ mm (1/8th of an inch) is sticking out. This represents the altitude at which most satellites, including the Space Shuttle, orbit above the Earth. Also, ask the students what distance they estimate Apollo 13 was from the Earth when they transmitted the message: "Houston, we have a problem." They will be quite surprised to find it was about two thirds of the distance between the Earth and Moon (2.55 meters or 2.02 yards).

Investigation 1.1c: Sizing the Sun and Planets

Students commonly have misconceptions regarding the actual sizes of objects within the Solar System. The numbers involved are usually meaningless, and the problem is compounded by misleading pictures and diagrams in textbooks and posters. Using a scale with 2.5 cm (1 inch) representing 4030 km (6500 miles) produces a model with the smallest possible Pluto and the largest possible Sun that can be dealt with in the classroom. The Sun must be created beforehand. Using tape and lengths of paper, construct a 3.45-meter (11.5-foot) diameter Sun and spray paint it a realistic yellow/orange color. You may again choose to use this activity as a demonstration or involve groups of students. The planets should be cut out of black construction paper, and the comparative sizes discussed. Then ask the students how big the Sun should be if it is on the same scale as the sizes of the planets. Answers will vary. After discussing the possibilities, bring out the 3.45-meter Sun and display the Sun on the floor or the wall.

SIZE OF PLANETS		
MERCURY	1.2 cm	(.5 inches)
VENUS	3.0 cm	(1.2 inches)
EARTH	3.2 cm	(1.2 inches)
MARS	1.7 cm	(.67 inches)
JUPITER	35.0 cm	(13.8 inches)
SATURN	30.0 cm	(11.8 inches)
URANUS	12.7 cm	(5.0 inches)
NEPTUNE	12.3 cm	(4.8 inches)
PLUTO	.63 cm	(.25 inches)

Have the students tape the planets on the Sun. The size difference is remarkable and always surprising! The Sun can also be constructed of cloth or felt. The planets can be made of paper or felt. They can be attached to the Sun by means of Velcro™, and then will last through many presentations. The slide set "Worlds In Comparison" gives accurate scale comparisons among Solar System planet and Moon sizes, as well as scales for geologic features (see Resource List for details.) RESOURCE

Core Activity 1.2: Unit Conversion

This activity is essential if your students are not familiar with units and unit conversion, otherwise it can be skipped. The next activity will require unit conversions, as do some of the other activities. This technique is used extensively in chemistry and physics courses. High school physics texts usually have several practice problems utilizing conversions, if you need a resource for other problems. It is a simple technique; however, students seem to have difficulty understanding that units cancel just like numbers, and that equal values (such as 60 minutes and 1 hour) can be made into fractions in order to convert units, as it is the same as putting the number 60 over the number 60, which is equal to one.

Answers to practice problems:

1. $\frac{150\ \cancel{\text{km}}}{\text{hour}} \times \frac{0.62\ \text{mile}}{1\ \cancel{\text{km}}}$ = **93 miles/hour**

2. $300\ \cancel{\text{miles}} \times \frac{1\ \text{km}}{0.62\ \cancel{\text{miles}}}$ = **4839 km**

3. $3{,}655{,}000\ \cancel{\text{cm}} \times \frac{1\ \cancel{\text{m}}}{100\ \cancel{\text{cm}}} \times \frac{1\ \text{mile}}{1690\ \cancel{\text{m}}}$ = **22.7 miles**

4a. $\frac{7\ \text{miles}}{\cancel{\text{second}}} \times \frac{3600\ \cancel{\text{seconds}}}{1\ \text{hour}}$ = **25,200 miles/hr**

4b. $\underline{7\ \cancel{\text{miles}}} \times \underline{1\ \text{km}} \times \underline{3600\ \cancel{\text{seconds}}}$ = **40, 645 km/hr**

4c. $\frac{7\ \cancel{\text{miles}}}{\cancel{\text{second}}} \times \frac{5280\ \text{ft}}{1\ \cancel{\text{mile}}} \times \frac{3600\ \cancel{\text{seconds}}}{1\ \text{hour}}$ = **133,056,000 ft/hr**

4d. $\frac{7\ \cancel{\text{miles}}}{\cancel{\text{second}}} \times \frac{1690\ \text{m}}{1\ \cancel{\text{mile}}} \times \frac{3600\ \cancel{\text{seconds}}}{1\ \text{hour}}$ = **40,546,800 m/hr**

5. $35\ \cancel{\text{years}} \times \frac{365\ \cancel{\text{days}}}{1\ \cancel{\text{year}}} \times \frac{24\ \cancel{\text{hr}}}{1\ \text{day}}$ = **306,600 ft/hr**

6. Sample for a 15 year old who sleeps ~8 hours//night.

$$15\ \cancel{\text{years}} \times \frac{365\ \cancel{\text{days}}}{1\ \cancel{\text{year}}} \times \frac{8\ \text{hours}}{1\ \cancel{\text{day}}} = \mathbf{43{,}800\ hours}$$

NOTE: You may need to explain to your students that in this problem one “sleep day” is equal to 8 hours. They are not looking for the total hours in 15 years (in which case they would use 24), they are looking only for the number of “sleep hours” in 1 “sleep day” in order to calculate how many hours of total sleep there are in 15 years.

Core Activity 1.3: String Model of the Solar System

This activity involves the construction of a scale model of the Solar System. The largest available distance in your school will determine the scale that you and your students will develop. You can construct it to fit the longest distance in your classroom, hallway, gym, or outdoors. If your students are not familiar with the technique for developing a scale, you may wish to determine the scale one day, and measure and construct the scale model the following day. A distance of 100 meters (109 yards) produces a small but visually effective model.

For younger students, construct a distance scale model only. For older, more sophisticated students, you may want to have them actually construct planets with correct scale models. The caveat is that unless you have 0.6 km (0.37 miles) of space with which to work, it is impossible to have the two scales the same. Having two different scales for distance and size may reinforce misconceptions about the size of the Solar System. If you choose to have the students calculate a scale for planetary diameters, refer to the radius distances in Investigation 1.1.

This activity also requires conversion of units. If your students are not familiar with this skill, you will need to use the unit conversion practice set in Core Activity 1.2. Since the distances to the planets are large numbers, this is an excellent time to introduce the Astronomical Unit (AU), as the AU is also an example of a scale. The distance from the Earth to the Sun is approximately 150,000,000 km (93,000,000 miles) and is designated as 1 AU. With this distance scale the distances from the Sun range from 0.39 AU for Mercury to 39.4 AU for Pluto—much easier numbers with which to work. (The students can use the actual distances and convert from kilometers to meters to see the difference themselves.) Another variation of this activity is to have separate groups of students use different locations so they will all have different-sized scale models. Then they can discuss the relative usefulness of each of the models.

Sample Scale based on a distance of 100 m (79 yards):

Scaling Factor (100 m/39.4 AU) = 2.54

Planet	Ave. Distance From Sun (AU)	Ave. Distance from Sun (kilometers)	Scale Distance from Sun (meters)	Scale Distance from Sun (yards)
MERCURY	0.39	58,000,000	0.39 x 2.54 = 0.99	1.08
VENUS	0.72	108,000,000	0.72 x 2.54 =1.83	2.0
EARTH	1.00	150,000,000	1.00 x 2.54 = 2.54	2.8
MARS	1.52	228,000,000	1.52 x 2.54 = 3.86	4.2
JUPITER	5.20	778,000,000	5.20 x 2.54 =13.21	14.4
SATURN	9.54	1,430,000,000	9.54 x 2.54 = 24.23	26.7
URANUS	19.2	2,870,000,000	19.2 x 2.54 = 48.77	53.4
NEPTUNE	30.1	4,500,000,000	30.1 x 2.54 = 76.45	83.7
PLUTO	39.4	5,900,000,000	39.4 x 2.54 =100.08	109.5

Core Activity 1.4: Mathematical Estimation of Sizes and Distances

This activity utilizes ratios and unit conversion to develop appropriately-scaled models of the Solar System. The first two questions prepare the students to develop their own scale for a Solar System model. You may decide to have them construct and demonstrate their models. If so, they should discuss what aspects of the Solar System are misrepresented in their models. Different groups can compare different scale models and discuss which ones are more useful and why. Table 1 .2A includes both meter- and kilometer-scaled distances. However, if the students select a small object to represent the Earth, they may not need to convert their scaled meters into kilometers.

RESOURCE

The 20 minute video entitled “Powers of Ten” is an excellent and powerful introduction to this topic. The first portion of the video “Cosmic Voyage,” relating to scale, can also be shown. It is less technical and more visually attractive. (See Resource List for details.)

Answers

1. (student estimation)

a) $\frac{15 \times 10^7 \cancel{km}}{14 \times 10^5 \cancel{km}} = 1.07 \times 10^2$ = **107 solar diameters**

b) 2 mm x 107 solar diameters = **214 mm**

c) $\frac{14 \times 10^5 \cancel{km}}{13 \times 10^3 \cancel{km}} = 1.07 \times 10^2$ = **107 times larger**

d) $\frac{2 \text{ mm}}{107}$ = **0.02 mm**

2. a) 107 solar diameters x 25 cm = **2675 cm**

$2675 \cancel{cm} \times \frac{1 \text{ m}}{100 \cancel{cm}}$ = **26.8 m**

b) $\frac{\text{diameter of Sun}}{\text{number of Earths per Sun}} = \frac{25 \text{ cm}}{107}$ = **0.23 cm**

c) 26.8 m x 40 = **1072 m**

d) 1072 m x 2 = **2144 m (2.144 km),** as the distance of Pluto from the Sun is the approximate radius of the Solar System

e) $\frac{420 \times 10^6}{14 \times 10^5}$ = **300 times larger than the Sun**

300 x 25 = **7500 cm (75 meters) diameter for Betelgeuse**

f) 2675 cm x 250,000 = 668,750,000 cm

$668{,}750{,}000 \cancel{cm} \times \frac{1 \text{ m}}{100 \cancel{cm}}$ = **6,687,500 m**

$6{,}687{,}500 \cancel{m} \times \frac{1 \text{ km}}{1000 \cancel{m}}$ = **6,688 km**

g) Any location 6,688 km away, or

$6{,}688 \cancel{km} \times \frac{0.62 \text{ miles}}{1 \cancel{km}}$ = **4147 miles away**

3. The answers will vary depending upon the object selected.

Poster Page: An Arm's-Length Reach into the Universe (the Voyagers)

Many people are now unaware of the spacecraft probes Pioneer 10 and 11, and Voyager I and II as they continue their journey out of the Solar System. Robotic spacecraft, exploration of the Solar System and other possible planetary systems, and so on, are rich topics for discussion, involving the complex relationship among national goals, international competition, economics, and logistics combined with the fascinating prospect of reaching worlds beyond our own. Is it feasible? What is the cost compared to other national expenses, such as war or human services or education? Is it important? There have been many technological advances within our culture that are a direct result of space research. Students would be surprised at the improvements they enjoy because of the NASA aerospace program, such as changes in medicine, engineering, and manufacturing. Many do not realize that such things as the amount of rainfall, the tracking of herds of migrating animals, and the rate of movement of the continental plates are now all measured from space.

The desire to explain our culture to any alien culture that might encounter the Pioneers and Voyagers suggests that science fosters human and hopeful endeavors. If your students launched a spacecraft, what would they include? Research all the information sent into space so far. Would they select sounds? What sounds? Would they select music? If so, would it be the same music? What do they think is representative of the planet? How would they convey, in an understandable fashion, the concept of what it is like to be human? Is that even possible? Is it even worth attempting? We bury time capsules under buildings and near statues in parks. What is buried? Why? Are time capsules in the ground similar to time capsules in space? What are we trying to say, and whom are we trying to tell?

SETI—the Search for Extraterrestrial Intelligence—is an active program. Is there other life orbiting around other suns within our galaxy? Should we spend time and resources on such a search? Several possible extrasolar planets have been discovered, all very unlike Earth. Research these planets and their suns. What types of life-forms could exist under those conditions? Could the same compounds survive there that have developed into complex living systems here on Earth? Do these planets meet your definition of a planet?

A plethora of creative writing and art projects, especially construction of models, are worthwhile extension activities associated with robotic exploration and the SETI program. Compiling a list of information and how to communicate it to alien beings involves consideration of multicultural and historical expressions of humankind.