Chapter 6: The Solar System
An Introduction to Comparative Planetology

Outline

6.1 An Inventory of the Solar System
6.2 Planetary Properties
6.3 The Overall Layout of the Solar System
6.4 Terrestrial and Jovian Planets
6.5 Interplanetary Debris
6.6 Spacecraft Exploration of the Solar System
6.7 How Did the Solar System Form?

Summary

Chapter 6 provides an introduction to our solar system as a whole. Inhabitants of the solar system are discussed and compared and theories for the formation of the solar system are given. This chapter lays the foundation for the next several chapters, which look in depth at our Earth, the Moon, the planets, and the Sun.

Major Concepts

- Solar system inhabitants
  - Sun
  - Planets
    - Sizes and distances
    - Properties
    - Classification: terrestrial and jovian
  - Asteroids, comets, and meteoroids
- Extrasolar Planets
- Formation of the solar system
  - The solar nebula contraction
  - Observations support theory
  - Planet formation
- Spacecraft Exploration of the Solar System

Teaching Suggestions and Demonstrations

Section 6.1

Review the scientific method here. Theories are modified when new information becomes available. Throughout recorded history, mankind has documented the existence of only five planets other than Earth itself. Not surprisingly, these are the planets visible with the unaided human eye. With the invention of the telescope and as new theoretical tools became available, the other three planets as well as the asteroids and comets became discoverable. Most of what we know now of the structure and evolution of the solar system has come about only within the last 150 years. Discuss this fact with the students and elicit their ideas on what new discoveries might be possible in their lifetime. This encourages free thinking and usually results in lively discussions, particularly in the area of the search for extra-solar planets and extraterrestrial intelligence.

Section 6.2

This is a good time to discuss (or review) the human mind's propensity to categorize objects in nature. This represents one of the thrusts of scientific investigation and has a history dating back to Aristotle himself. Categorization is one way for us to break-down the complexities in nature into more manageable portions for analysis.

Sizes and distances are important in the study of astronomy. If you haven't already done so, quickly review the metric system to make sure students are familiar with the prefixes and have a fairly good grasp of the different units. Give examples of a broad range of lengths; the book and video *Powers of Ten* is an excellent introduction to the size and scale of the universe and objects within it.

It is common for students to confuse **density** with weight. ➲ **DEMO** Bring in a variety of objects, such as a wooden block, a marble, a rock, and a styrofoam cube and demonstrate finding their densities. The volumes of objects with irregular shapes can be determined by immersing them in water. This demonstration is most effective if at least one high-density object has a lower mass than a low-density object. Try using a small marble and a large wooden block.

➲ **DEMO** Other properties can be explored with readily available objects. As an example, bring in two globes of different diameters. With these two globes, representing two different size planets, you can also demonstrate differences in rotational period and the tilt of their respective rotational axes.

Section 6.3

Most likely your students will have never seen a **scale model of the solar system** that has the same scale for both sizes and distances. If you choose a scale so that the model can be laid out in a room or even a long hallway, the inner planets are all indistinguishably small dots. If you choose a scale that clearly shows sizes, the planets must be so spread out that it is impossible to see them all at once. It is a very useful and enjoyable exercise to have students construct scale models. Try dividing the students into groups and give them different challenges. For instance, give one group a large collection of spherical objects of different sizes. You could include various balls used in sports (basketball, volleyball, soccer ball, baseball, golf ball, hackysack, Ping-Pong ball) as well as other larger (beachball) and smaller (bead, chickpea, pinhead) objects. The challenge for the group is to use any of the objects they wish (as well as others they can find in the classroom) to create a model showing the *sizes* of the planets to scale. When they are done, ask students to also calculate where a couple of the balls would be placed if the model were to show distances to the same scale. Have the students refer to Table 6.1 for the above exercises.

Meanwhile, give another group a roll of cash register tape and send them out to a hallway to construct a model showing the *distances* of the planets to scale. When they are finished, ask them to calculate the sizes of a few planets to the same scale. A third option is to give a group a road map of your state and ask them to place the Sun at one edge and Pluto as far away as possible. They should then calculate where the other planets would lie and how big they would be.

If your class structure does not allow for group work of this type, you can modify the activities into demonstrations. ➲ **DEMO** Bring in the collection of balls, hold up the one you have designated to be Earth, and ask students to guess which objects could be used to represent the other planets and the Sun. Or, assign planet roles to various students and ask them to place themselves across the classroom such that their distances are to scale.

For purposes of scale, use the following rules of thumb: The diameter of Earth is about 1/100th the diameter of the Sun and is situated about 100 Sun diameters distant. Jupiter is about 1/10th the Sun's diameter and is about 560 Sun diameters distant. Pluto is less than 1/100th the Sun's diameter and is about 4000 Sun diameters distant. So plan accordingly when performing scale model demonstrations or activities.

Weather permitting, a very enjoyable and engaging modification to the above-described activities can be performed outdoors. First, consider a scale model where the Sun is represented by a basketball. It is fun and surprising to start with this scale, which places a BB representing Earth about 30 meters away from the basketball. Place each of the four terrestrials accordingly then ask for volunteers willing to carry the outer planets to their appointed distances. Tell them to start walking and you will yell for them to stop when they are at the appropriate distances (it is even more entertaining to let them know that this would be the only need they would have all semester for the use of their cell phone in class). Knowing yourself that Pluto would be more than 1 km away, let them get some distance away (use your own discretion) before calling them back to explain how far they would have had to have walked to achieve the proper scale. At this point select a more appropriate size ball, such as a softball, to represent the Sun. In this case, Mercury would be smaller than the head of a pin and located at a distance of about 41 Sun diameters away, or about 41 cm away. The Earth would be smaller than the head of a pin and situated about 11 meters away. Jupiter, represented by a small marble 1 cm in diameter would be located about 56 meters away. Even at this scale, Pluto would be imperceptibly smaller than the head of a pin and located over 400 meters away so I usually end the exercise with Saturn.

These models will help to dispel typical student misconceptions. For instance, many students believe Jupiter is about halfway out to Pluto, when in fact it is closer to halfway to Saturn and only about an eighth the way to Pluto. Students also often enter introductory astronomy classes thinking that Uranus and Neptune are about the same size as Jupiter and Saturn, when in fact they are less than half the size. Emphasize the difficulty encountered in attempting to show sizes and distances of the planets to the same scale.

Section 6.4

The classification of the planets into **terrestrial** and **jovian**, with Pluto belonging to neither class, will be fairly easy for students to understand. Before showing them Table 6.2, re-introduce Table 6.1 and ask them for suggestions of characteristics used to compare and contrast the two types of planets. They will probably be able to generate most of the items in the table, with the exception of the magnetic-field strength and the rotation rate. Try splitting the class into groups according to selected planetary properties. Have each group categorize the planets according to their assigned property and report their results to the class, preferably in a table that they can display on the blackboard or overhead projector. For a majority of the properties, each group will have similarly divided the planets into two clear categories.

Section 6.5

The main categories of solar system debris include **asteroids, meteoroids,** and **comets**. Spend some time comparing and contrasting these different types of objects. Calculate the size of a typical asteroid to the same scale as you used in a previous scale model. It is interesting to look not only at the characteristics of the different objects, but also at how we perceive them from our place on Earth and at how they have impacted us.

A very common description of asteroids is that they look like potatoes. ➲ **DEMO** Bring in a couple of potatoes to use as models. Using a typical asteroid size, calculate the scale of the model.

Students often believe that the asteroid belt is very crowded with little room between neighboring asteroids. Hand one of the potatoes to a student and calculate how far away she needs to stand from you, using the same scale you used for the size of the asteroid, to represent a typical distance between asteroids. Students will probably guess that both potatoes should be in the classroom, when in fact they should be perhaps 1000 km apart!

Be sure to distinguish among the terms **meteor, meteorite,** and **meteoroid**. Ask your students if any have ever watched a meteor shower, and encourage them to try to view one—given the right conditions, they can be spectacular! (See Table 14.1 for a list of major meteor showers.)

Comets can also be quite impressive. Point out that the **comet's tail** is produced by the solar wind, not by the comet's motion through space. Comets are often described as "dirty snowballs." ➲ **DEMO** A model of a comet can be made by freezing a mixture of water, fine dirt, and soot. Show slides or photos of famous comets. Pick a well-known comet, such as Halley's Comet, and use its period with Kepler's third law to calculate the semi-major axis of its orbit.

Section 6.6

Briefly discuss the **spacecrafts** that have visited the planets (refer to table 6.3), and try to give students a feel for the complexity of the missions. One obvious point is that the spacecrafts are aiming for moving targets! The *Discovery 6-1* box on gravitational slingshots is very interesting. Also have students consider what happens to the spacecrafts after their missions are complete. *Galileo* was directed into the planet Jupiter at the end of its lifetime. However, the *Voyager* spacecraft wandered out of our solar system. The book *Murmurs of Earth: The Voyager Interstellar Record*, by Carl Sagan and others, details the record of pictures and sounds constructed to send along with the craft should it ever be found by extraterrestrials. The idea of other intelligent beings possibly finding a spacecraft from Earth is very interesting to students. Impress upon them that the process of deciding what to include in the record is fascinating by itself. If you have time, divide students into small groups and charge each team with deciding upon a list of pictures and sounds they would choose to represent Earth. You could also assign this as a group project to be completed outside of class.

Emphasize to students the excitement surrounding the **discovery of Uranus**. This event was, after all, the first time a new planet had been *discovered* rather than just known from ancient times. The **discovery of Neptune** is also an important event in the history of science, because it was actually predicted after astronomers observed Uranus's orbit and determined something was influencing it. Contrast the two types of discoveries and ask students if they can think of other examples of each.

Section 6.7

Before discussing the formation of the solar system directly, review some of the **major characteristics of the solar system** that must be explained by, or at least be compatible with, a theory of its origin. For instance, all the planets orbit in the same direction around the Sun, and most rotate in this same direction as well. Further, they lie (more or less) in the same plane.

Outline the stages in the **formation of the solar system** for students. There are lots of new terms introduced in the text; go over them carefully. Define and discuss **angular momentum**; students will probably not be familiar with it unless they have taken physics. However, they will be familiar with the results of the law of conservation of angular momentum. ➲ **DEMO** If any of your students are dancers, ask them to demonstrate a spin in which the arms start far from the body and end up close. Students can try to think of other examples of the conservation of angular momentum as well. ➲ **DEMO** One classic demonstration involves a rotating stool and a bicycle wheel. Ask a student to sit on a rotating stool and hold a bicycle wheel vertically. With the stool stationary, give the wheel a spin. Then ask the student to rotate the axis of the wheel so that the plane of the wheel is now horizontal. Because the angular momentum of the system is changing, the student and stool will rotate in such a manner as to conserve angular momentum.

Student Writing Questions

1. You have just been given a very unique spaceship that takes one million kilometer "steps" or jumps each minute. You now have the opportunity to explore the solar system with it. (The ship holds almost unlimited provisions and fuel is never a problem!) Please do not assume that the planets are all neatly lined up, but rather scattered about on various sides of the Sun. Describe the layout of the solar system you are about to explore and the route of your journey. How long will the trip from one planet to the next take? How long will you be gone from Earth? Would you dare try a trip to the nearest star?

2. You have just come home after an inspiring lecture in astronomy and have just learned how the average density of a planet is determined. Unfortunately, this subject comes up in front of your little sister who, unlike average little children who always ask "why," likes to ask instead "How do you know that?" She is never satisfied with "My professor said so" type of responses. Can you answer her repeated question "How do you know that?" on the topic of the average density of a planet? Just how many "How do you know that?" can you answer (assuming no harm comes to your sister) during this episode?

3. The objects in the solar system closest to Earth have always been important to us because of their visibility, particularly in our mythology, establishing calendars, and in some religions. What if life had arisen on a moon around Saturn or one of the outer jovian planets? How might this have changed our world view? Think in terms of the much greater distances to the other planets and even the Sun. What effect would multiple moons make rather than our one, dominant moon?

4. Investigate the names of the days in the week and find what the astronomical connections are to the name. What languages are involved? Why are there 7 days in the week?

5. Most of the planets of the solar system have nearly circular orbits. What would be the effects of a large planet, like Jupiter or Saturn, having a highly elliptical orbit? Assume its perihelion is 0.3 A.U. and aphelion is where the current orbit is. Would Earth or its life be affected by this?

Answers to End of Chapter Exercises

Review and Discussion

1. In our solar system there are 9 planets, 1 Sun, 136 (known) moons, asteroids, meteoroids, comets, and interplanetary dust. There are at least two basic types of planet, terrestrial and jovian, found in the inner and outer parts of the solar system. The terrestrial planets are all found close to the Sun, within 1.5 A.U. The jovian planets are scattered out at much greater distances, from about 5 to 30 A.U. Pluto, which is neither a jovian or terrestrial planet, is at about 40 A.U. The space between these objects is a better vacuum (space void of matter) than can be produced on Earth, although it contains much more material in the form of dust and gas than found between the stars.

2. Comparative planetology contrasts and compares the properties of objects throughout the solar system. Typical examples are the comparison of Mars and Venus to the Earth or Mercury to the Moon. By looking for similarities, new objects can be understood; by looking for differences, new processes are revealed.

   By understanding the similarities and differences among the bodies of the solar system, it will be possible to understand its origin and evolution. In the end, we might hope to understand the Earth much better than we do now. By seeing how other bodies formed and developed we may be able to understand how Earth developed an environment that has been so supportive of life. It is not clear at this time that other bodies have done this nor is it understood why they have or have not.

3. A planet's mass is determined using one or more of its moons and Kepler's third law. But this law requires that the size of the orbit be known and the only way this can be determined is if the distance to the planet is known.

4. The orbits of the planets are mostly in the same plane. Many of the orbits of moons are near this same plane. Minor bodies like asteroids and some comets have orbits in this plane. The rotation and revolution of most bodies are the same. Most asteroids are in the asteroid belt. Comets are mostly in the Oort Cloud.

5. Mercury and Pluto have orbits tilted to the rest of the planets. Venus and Uranus have unusual rotations and Uranus is quite tilted over. Some moons have retrograde orbits. Comets from the Oort Cloud come in from all angles. Collisions by meteoroids and comets occur randomly.

6. The terrestrial planets are Mercury, Venus, Earth, and Mars. They are called terrestrial because they are similar to the Earth in their physical and chemical properties.

7. The jovian planets are Jupiter, Saturn, Uranus, and Neptune. Jovian means Jupiter-like; the jovian planets have Jupiter-like properties.

8. Three differences between jovian and terrestrial planets: (1) location in the solar system, (2) size of the planets, (3) density. The terrestrial planets are in the inner 1.5 A.U. of the solar system; the jovian planets are scattered from 5 to 30 A.U. The jovian planets are much larger than the terrestrial planets. Terrestrial planets have a much higher density than the jovian planets, which indicates a fundamental difference in composition. Terrestrial planets are rocky, jovian planets are made up of light elements.

9. Pluto is not a jovian planet, nor a terrestrial planet, because it is small and icy and has properties of neither type of planet.

10. Asteroids and meteoroids are important because they often contain material that has undergone little change since the solar system was formed. The surface material of the Earth and Moon, for instance, has changed greatly over time, thus little is known about the original conditions under which they were formed.

11. The ices that make up a comet become gaseous as the comet nears the Sun. These gases emit light which can be analyzed. Comets also release dusty particles which reflect sunlight and reveal information about their size and composition.

12. Over the last several centuries, telescopes have revealed many of the objects of the solar system that are invisible to the naked eye. Often, little but the existence and motion of these

bodies could be observed. But space probes, during the last few decades, have revealed what these objects really look like. Instruments on board the probes also tell us much about other properties, such as the magnetic fields and compositions, that would be impossible to observe from Earth.

13. Rocket engines are sometimes insufficient to propel spacecraft to the speeds needed to reach the outer planets. Gravity assists allow a spacecraft to "rob" a planet of a tiny bit of its orbital energy to boost its speed. This method is also a cheap solution to this sort of problem.

14. All planets have been visited by spacecraft with the exception of Pluto. Spacecraft have landed only on Venus and Mars.

15. Both *Galileo* and *Cassini* were launched by the Space Shuttle. It could not carry the booster rocket needed to move these probes out of Earth orbit and send them directly to Jupiter and Saturn. Gravity assists were the only way to get their speed high enough.

16. The answer to this is rather speculative. Smaller, cheaper, faster is the new policy. One benefit is that a probe failure is not as devastating as with the big missions. Results come back faster, which helps in the planning of future missions.

17. Interstellar dust within the early solar nebula is the key ingredient for the modern condensation theory for the formation of the solar system.

18. The solar system contains rocky/metallic planets nearer to the Sun and gaseous planets further out. Additionally, the rocky asteroids, existing primarily in the inner (warmer) regions of the solar system and the icy comets which exist and originate in the far reaches (cooler regions) of the solar system provide further evidence in support of the condensation theory.

19. The jovians are much more massive than the terrestrials since they have spent more time accreting mass. Additionally, they had more material available from which to collect their matter.

20. The terrestrial planets consist of heavier elements because the higher temperatures where they formed prohibited lighter elements (such as large quantities of gases) from condensing out of the solar nebula as efficiently as the outer planets, which formed in much cooler regions.

Conceptual Self-Test

1. T
2. F
3. T
4. T
5. F
6. T
7. T
8. F
9. F
10. T
11. A
12. D

13. A
14. B
15. C
16. A
17. A
18. B
19. B
20. D

Problems

1. At 9.5 earth radii Saturn's diameter is 2 × 6400 km × 9.5 = 121,600 km. The angular diameter can be calculated as follows: 121,600 km = 9.5 × 150,000,000 (ang. size / 206,000). Angular size = 17.6".

   Calculate Titan's orbital radius in A.U. using the previous method and appropriate units. Radius = 9.5 (3.1 / 3438). Orbital radius = 0.00857 A.U. To use Kepler's third law in solar units, find Saturn's mass in solar masses. 95 × 1/330,000 = 0.000285 solar masses. $P^2 = (0.00857\text{ A.U.})^3 / 0.000285$, P = 0.047 days = 17 days.

2. (a) For Earth, assume your mass is 100 kg. Using Newton's law of gravity;

$$F = \frac{6.67\times10^{-11}\times5.97\times10^{24}\times100}{\left(6.378\times10^{6}\right)^2}$$

F = 978 N. With 4.45 N in a pound, this gives

F = 220 lbs

(b) For Mars

$$F = \frac{6.67\times10^{-11}\times0.11\times5.97\times10^{24}\times100}{\left(0.53\times6.378\times10^{6}\right)^2}$$

F = 383 N. With 4.45 N in a pound, this gives

F = 86 lbs

(c) Here's another approach. The gravitational acceleration of a body on its surface depends on the mass of that body and inversely on the radius of the body squared. The weight of an object depends directly on this acceleration.

$$\text{Weight} \propto \frac{0.0002}{0.073^2}\text{ Weight on Earth}$$

$$\text{Weight} \propto 0.0375\text{ Weight on Earth}$$

A 100 kg person would weigh 220 lbs on Earth. On Ceres, the weight would be:

$$\text{Weight} = 0.0375 \times 220 = 8.25\text{ pounds}$$

(d) Similarly, for Jupiter, the result would be 558 pounds.

3. Use the information provided in Table 2.1. Perihelion distance is given by $a(1-e)$ and aphelion distance is given by $a(1+e)$.

	Mercury	Mars	Pluto
Perihelion distance	0.307	1.382	29.73
Aphelion distance	0.467	1.666	49.33

4. Using *More Precisely 1-4*, calculate the angular size of Neptune = 29.1 A.U. (2.3 / 206,000) = 0.000325 A.U. = 48,700 km. Half of this is its radius, 24,400 km.

   By the same method, Triton's orbit is 0.00237 A.U. Use Kepler's third law in solar units $(5.9 / 365)^2 = (0.00237)^3 / M$. $M = 0.0000509$ solar masses or 1.0×10^{26} kg.

   Density = 1.0×10^{26} kg / $4/3\pi(2.44\times10^7)^3$. Density = 1650 kg/m^3.

5. The total mass of all asteroids would be 7000×10^{17} kg = 7×10^{20} kg. The mass of Earth is about 6×10^{24} kg. Comparing these, 6×10^{24} kg / 7×10^{20} kg = 8,600. Thus, Earth has 8,600 times more mass than all the asteroids combined. As we see them today, the asteroids would not make up much of a planet!

6. 3000 kg/m^3 = 10^{17} kg / $4/3\pi(R)^3$. R = 20,000 m = 20 km. Diameter = 40 km.

7. From Kepler's third law, $200^2 = a^3$, a = 34.2 A.U. Perihelion distance is $a(1-e)$, solving for e gives 0.985. Aphelion distance is $a(1+e)$, which gives 67.9 A.U.

8. As of January, 2004, *Mariner 10* has been orbiting the Sun for 30 years. With an orbital period of 176 days, this gives 30 × 365 / 176 = 62 orbits.

9. At perihelion, the spacecraft is 1 A.U. from the Sun. At aphelion, it is 1.52 A.U. from the Sun. So, 1 A.U. $= a(1-e)$ and 1.52 A.U. $= a(1+e)$. There are two equations and two unknowns, so we can solve for both a and e. Using basic algebra, we get a = 1.26 A.U. and e = 0.21. Now, use Kepler's third law, $P^2 = a^3$, to compute the orbital period, P. $P = \sqrt{a^3} = \sqrt{1.26^3} = 1.4$ years. The time required to travel from Earth to Mars is simply half of the orbital period or 0.7 years.

10. The Earth is at 1 A.U. and Mars is at 1.52 A.U. (using its semi-major axis as an average distance). The major axis of the orbit must be the sum of these or 2.52 A.U. The semi-major axis of the orbit is half this or 1.26 A.U. The distance between the Sun and the center of the orbit is the semi-major axis minus the perihelion distance or 1.26 - 1 = 0.26 A.U. Eccentricity is this latter distance divided by the semi-major axis; 0.26 / 1.26 = 0.21. Using Kepler's third law to determine the orbital period gives $P^2 = 1.26^3$. P = 1.4 yrs.

11. This sketch should show Earth passing up Mars and the trajectory arcing out from Earth and catching up with Mars. Earth will have moved over half of its orbit; Mars will have moved almost one third of its orbit.

12. The distance between Earth (1.0 A.U. from the Sun) and Saturn (9.5 A.U. from the Sun), at closest approach is 8.5 A.U. 1 A.U. is about 150 million km, so 8.5 A.U. is about 1.3×10^9 km. Light (and radio waves) travel at 300,000 km/s and so will travel the Earth-Saturn distance in 1.3×10^9 km / 300,000 km/s = 4250 s or 71 minutes. The round trip takes 142 minutes or 2 hours and 22 minutes. Mission Control on Earth cannot maneuver spacecraft in real time because it would take over 2 hours for a command to be sent and a response returned; the delay is too long for maneuvering a high-speed spacecraft.

13. The initial rotation rate, ω_1, is 1×10^{-7} years and the initial diameter, d_1, is 0.2 Ly or 12,900 AU. Since mass is constant, we have $\omega_1 \times d_1^2 = \omega_2 \times d_2^2$ where ω_2 and d_2 are the final rotation rate and diameter respectively. For Part a, given that $d_2 = 100$ A.U. and solving for ω_2, we have $\omega_2 = 1.7\times10^{-3}$ revolutions per year. This gives an orbital period of 600 years. For part b, we set $d_2 = 2$ AU. Using similar algebra as in part a, we get an orbital period of about 0.24 years..

14. If the Earth's rotation rate were twice what it is now, then its angular momentum would double as well. Regarding the second part of the question, we need to know how the velocity would change given the Earth being situated in a larger orbit. If Earth's orbital distance were to double, then, applying Kepler's third law, we would see that its orbital period would increase by a factor of the square root of 2^3, or 2.8 years. Since speed is simply $2\pi R/T$, where R is the orbital radius (now twice that of the original) and T is the orbital period (now 2.8 times the original), we have the new speed as 0.7 times the original speed. Since the radius also doubles and the orbital angular momentum is a function of the speed and radius, then this factor would double as well. So, the final orbital angular momentum must change by a factor of 1.4.

15. For density to remain constant, the mass must increase with the cube of the radius. Therefore, if the radius is doubled, then the mass must increase by a factor of 8. Now, the force of gravity on the planet surface is proportional to mass/radius^2. If the radius is doubled, and recall that the mass increases by a factor of 8, then the gravitational force would increase by a factor of $8/2^2$, or 2.

Resource Information

Student CD Media

Movies/Animations
Beta Pictoris Warp Animation
An Astronomical Ruler
The Terrestrial Planets I
The Gas Giants I

Interactive Student Tutorials
None

Physlet Illustrations
Mass of Planet from Kepler's 3rd Law
Gravitational Slingshot

Transparencies

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Materials

Supplies needed to create models of the solar system include various-size balls and other round objects and meter sticks.

The National Geographic Video *Asteroids: Deadly Impact* includes fascinating information about the study of impacts and an interview with Eugene Shoemaker.

A bicycle wheel and rotating stool can be used to demonstrate conservation of angular momentum.

The Astronomical Society of the Pacific has several good resources for teaching about the solar system, including maps, posters, models, and a DVD/Videotape set entitled *The Planets*.

Project Star has a solar system scale model kit (item PS-05).

Suggested Readings

Aguirre, Edwin L. and Lyster, Timothy. "Walking tours of the solar system: three scale models of the Solar System." *Sky & Telescope* (Mar 1998). p. 80. Describes three exhibits which demonstrate the solar system to scale.

Basri, G. "What is a Planet?" *Mercury* (November/December 2003). p. 27. Article explores the definition of "Planet." Many nice diagrams, charts and images comparing various planet-like objects. Very timely with regard to recent discoveries of Kuiper Belt and Oort Cloud objects.

Binzel, Richard P. "A New Century for Asteroids." *Sky & Telescope* (July 2001). p. 44. A review of what we now know about asteroids since Ceres was discovered 200 years ago.

Bobrowsky, M.; Sahu, K. C.; Parthasarathy, M.; García-Lario, P. "Birth and Early Evolution of a Planetary Nebula." *Nature* **392**, 469 - 471 (02 Apr 1998), Letters to *Nature*

Cameron, A. G. W. "Planetary science: Birth of a Solar System." *Nature* **418**, 924 - 925 (29 Aug 2002). Outlines new data suggesting modifications to existing planet formation theories.

Cowen, Ron. "The day the dinosaurs died." *Astronomy* (Apr 1996). p. 34. Discusses evidence associating the crater Chixulub, the K-T boundary, and the extinction of the dinosaurs, and describes possible scenarios of how the impact actually resulted in the extinctions.

Frank, Adam. "Crack in the clockwork: the solar system may have lost several planets, and Mercury or Mars might be the next to go." *Astronomy* (May 1998). p. 54. Discusses the idea that the solar system may be a chaotic system.

Gluck, P. "MBL Experiment in Angular Momentum." *The Physics Teacher* (April 2002). p. 230. Studies the loss and conservation of angular momentum using a small direct current motor as generator.

Hartmann, William K. "The great solar system revision." *Astronomy* (Aug 1998). p. 40. Summarizes the highlights of 25 years of planetary exploration.

Johnson, Torrence V. "The Galileo mission to Jupiter and its moons." *Scientific American* (Feb 2000). p. 40. Summarizes the highlights of the first five years of the Galileo Mission.

Kring, David A. "Calamity at Meteor Crater." *Sky & Telescope* (Nov 1999). p. 48. Discusses what we can learn about Earth impacts from studies of Meteor Crater in Arizona.

Malhotra, R. "Migrating Planets: Did the solar system always look the way it does now?" *Scientific American* (September 1999).

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Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: