May 2002 Number 21

Big Picture Science Newsletter

The science information newsletter for Montessori teachers of 6-15 year-olds

Approaching the solar system

Of the astronomy subjects I've researched this year, there is, by far, more material available on the solar system than any other topic. You won't have trouble finding pictures and facts about the planets. The challenge will be in filtering poor quality "information" and helping children use good information to form an interesting, realistic picture of the other worlds that orbit the Sun.

Children may wish to investigate the space probes that have enabled us to gather all this data. See the resources for information on our solar system explorations, which I do not address here.

I have decided to concentrate on the origin of the solar system and the planets. Knowing the events in the solar system's formation will make it easier for students to understand and remember the components and their properties. It helps us appreciate our unique, life-supporting planet.

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The Formation of the Solar System

Help students picture the origin and orbits of the planets

Our solar system formed about 4.6 billion years ago. While no one was there to see the events, astronomers have many clues from which they have developed the most likely scenario.

Students become acquainted with some aspects of the solar system at an early age. Many can recite the names of the planets, often using a mnemonic such as "**M**y **V**ery **E**ducated **M**other **J**ust **S**erved **U**s **N**ine **P**izzas" to help them remember "Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

Elementary students are ready to address **how the solar system formed.** They may hear a brief outline of the process in the first Great Lesson, but many will be interested in finding more of the details. The formation of the planets is a story that we are still writing. Astronomers make more discoveries and have more information to explain each year. The basic outline is fairly well established, however, and we have working hypotheses about the formation of all components of the solar system.

To get a better grasp of the whole arrangement of the solar system, children need **accurate diagrams** that show the three-dimensional aspect. They need to **make their own models**, so that they can see the immense distances involved and comprehend the relative sizes of the planets. See page 4 for a helpful website on solar system modeling.

It is important for students to **understand the forces** that formed the solar system and presently shape it. Gravity plays its usual central role, pulling matter together. The Sun's gravity holds the planets in their orbits. Each planet's gravity gives it its spherical shape. The gravity of large planets can cause strong tides on their moons or affect the orbits of their neighbors. Angular momentum and inertia keep us spinning around, along with the lack of friction in space. Density is a big part of the story, so you may wish to review it or add activities to explore the concept of density.

Earth is our own special case, and of course, the planet about which we know the most. The story of the formation of Earth and its Moon is a dramatic one. Scientists are still trying to figure out the origin of Earth's oceans. See page 7 for more on Earth's water.

The **other planets are best imagined in comparison to Earth**. Figures on the surface gravity of other planets will not mean as much as seeing how much you would weigh if you were there. See page 8 for a website that calculates this information for you. Be sure to scroll on down to the last section, which shows your weight on other stars, including a neutron star. Does this mean I'll have to emigrate to Venus to achieve my ideal weight? No point – my slacks still wouldn't fit.★

The Basic Story of the Solar System's Origin

Here's an introductory story of the solar system's origin, based on the theory most astronomers use, the condensation theory of solar system formation. It starts with the contraction of the solar nebula and describes basic planet formation. The solar nebula is the cloud that became our solar system.

The story: About 5 billion years ago, in one of the spiral arms of the Milky Way galaxy, a **huge cloud of dust and gas** began to **collapse and spin**. We don't know exactly what caused it to collapse, but it could have been the explosion of a supernova in that area. Whatever the cause, the particles began to move closer together under gravity's pull. Gravity pulled a **large mass** of material **into the center** and the cloud contracted and **spun faster**. The nebula was mostly hydrogen and helium. As most of the matter was pulled to the center, the rest **flattened** into a whirling pancake shape around the big lump in the middle.

The pancake-like, **disk** was **made of** mostly of **gas**, with small dust particles of **metals**, **rock**, and **ice**. Gravity gradually compacted the lump at the center and it heated up from the compression of the gases. The ice close to the center melted and vaporized. After a time, the lump got so hot that in its center, hydrogen atoms were squeezed into helium atoms. It became a star, our Sun. When the Sun began to shine, the outpouring of its radiation and a very strong solar wind of particles swept the gases from the central part of the disk to its outer edges.

The outer areas of the disk had been cooling. The materials had begun to **condense** around dust particles and form larger clumps of **rock** and, farther away from the Sun, **ice**. (The ice was made of ammonia and methane, as well as water.) The clumps got bigger and bigger, until after a time they grew to the size of boulders and even small mountains, all whirling around the about-to-be Sun. We call these **planetesimals**. They began to bump each other and sometimes if they hit just right and not too hard, the planetesimals stuck together. The process of planetesimals sticking together and making larger objects is called **accretion**. As the planetesimals joined, they became **protoplanets**, which were about the size of our Moon and which formed the cores of the planets. The protoplanets gathered nearby planetesimals.

Very early in the formation of the solar system, the core of a large planet began to accrete about 5 times the distance of the Earth from the Sun, where it was cool enough to have ice as well as rock. This planet's core grew quickly and so its gravity was strong enough to amass gases before the Sun swept them out of the disk. This became the **giant planet**, **Jupiter**. Jupiter's gravity was so strong that no other planet could form close to it. The asteroid belt between Jupiter and Mars is left over planetesimals. Jupiter kept pulling them apart and pulling material from that orbit, so they never formed a planet. Jupiter did us a great service because it shielded Earth from many stray planetesimals and comets (and it still does).

Later, as protoplanets accreted in the rest of the disk, their gravity swept up the loose planetesimals, leaving mainly one large body in their orbits. All planets had a **dense rain of rocky planetesimals early** in their history. The **cratered faces of our Moon and Mercury** show evidence of this. The surfaces of the Moon and Mercury haven't changed much since they formed, so they preserve a record of early times. As most of the planetesimals were used up, the rain of rocky bodies slowed, and then almost stopped. A small meteorite still hits the Earth occasionally. The **protoplanets themselves collided** on rare occasions with spectacular aftereffects, including the tilts of planets' axes and the formation of Earth's Moon.

Earth and the planets near the Sun formed from the rocky grains that were left after the ice melted and the gases were swept away. These planets are **denser than the outer planets**, but they are too small (and probably formed too late) to hold the light hydrogen and helium gases that swell Jupiter and Saturn. They have **metal cores** that are very dense, with lighter **outer layers of rock**. (Similarly sized hand specimens of iron and granite would be useful for the children to hold at this point.)

Out beyond Jupiter, Saturn formed. Like Jupiter, it has a small rocky core with a big layer of gases on the outside. **Jupiter and Saturn** are sometimes called **gas giants**. Later on and farther out two more giant planets, **Uranus and Neptune**, formed. They are sometimes called **ice giants**, since they are made more of ice than of gas. Most of the gas had left the disk before they formed.

The last planet in the solar system is **Pluto**. It is **tiny** compared to its neighboring giant planets. It is even tiny compared to the rocky inner planets. Pluto is probably a **captured plantesimal** rather than a planet that formed in its present orbit. Its orbit is different from the other planets, more tilted out of the disk region and more elongated. Some people don't even consider Pluto a planet.

So our solar system has a star in the center, our **Sun**, which **has more than 99% of the mass** in the solar system. Near the Sun four rocky planets orbit, Mercury, Venus, Earth, and Mars. Then there is a ring of rubble, planetesimals that never stuck together into a planet, which we call the asteroid belt. Four giant planets, Jupiter, Saturn, Uranus, and Neptune, come next. Then little Pluto is tacked on at the end.

Or is it the end? Not quite. A region of sparse comets and planetesimals called the **Kuiper** (KYE-per) **Belt** lies beyond Pluto. It is more or less within the outline of the pancake-like disk and ends about three times the distance of Neptune from the Sun. Comets that return to the Sun in less than 200 years, like Halley's Comet, come from that region. Far beyond that, 50,000-100,000 times the distance of the Earth from the Sun, a sparse cloud of comets forms a sphere around the rest of the solar system. It is called the **Oort Cloud**, and like the Kuiper Belt, it is named after its discoverer. Occasionally a comet leaves the Oort Cloud, travels inward, passes near the Sun, and then returns to its faraway home. We never see it again because it can take many thousands of years to return.

Picturing the Solar System

For students to understand the story of the early solar system they need to know about its present state. To help you acquaint students with the current solar system you will need to have a **good diagram that shows the spatial relationships of the planets and the Sun**. It should show **eight planets orbiting more or less in the same plane**, with **Pluto's orbit tilted and more elongated**. It may take two diagrams to show this, one view of the inner solar system and one that shows the outer planets, since these can be shown clearly only at two different scales. If your diagram shows the direction the planets orbit, this is helpful. If not, you can point out that the planets orbit counterclockwise when viewed from above the Earth's North Pole. Also note that planets (except Venus) rotate in that direction as well.

Whatever diagram or poster you use, take time to **explain how the diagram differs from the real thing**. Note that the diagram shows the lines of the orbits, lines that do not appear in space. The orbits are really much farther apart and are not equally spaced. The diagram may show a perspective view of the planets, in which the Sun appears small in the distance. A scale model of the Sun and planets will correct any misconceptions students have about the true size relationships.

Here are some sources of good illustrations for the solar system story.

The Astronomical Society of the Pacific sells an attractive poster of the solar system. It is item AP 400 in their catalog. You can order via phone at 1-800-335-2624 or online at www.astrosociety.org

Books (see p. 8 for complete references) with useful illustrations include: Brimmer (p.4-5), Mitton (pp.10-11), Levy (pp.10-13), Kerrod (illustrates the formation and current solar system); and Rau (p.14). Encyclopedias are another good source. For Internet sites, see page 8.

Modeling accretion

Children will benefit from seeing accretion in action. You can show this process with modeling clay or play dough. First make many small, irregularly shaped pieces to represent the first clumps of matter that condensed from the solar nebula. Sprinkle these on a tray. Stick 3-4 of these together. This is your model planetesimal. Make more "planetesimals". Bump two of the planetesimals together and round them a bit, just as gravity rounded the planets. Repeat this until you have a ball. Roll your ball, a model protoplanet, across the tray. As travels near other "planetesimals", they will be "attracted" by its gravity. Move them over to the protoplanet and press them into the ball. You have modeled planet formation.

How are stars different from planets?

It should be clear that stars are much bigger than planets, but there is also a basic difference in the way the two types of bodies form. Stars form from gas, with a tiny trace of dust. Gravity pulls the whole mix into a ball all at the same time. Planets accrete a little at a time. They can have a core that is very different from their outside. Stars have similar compositions, almost all hydrogen and helium. Planets may have a wide range of compositions, from mostly metal and rock to largely gases. Jupiter is sometimes called a failed star, since it is so big, but it appears to have a rocky core with a layer of compressed solid hydrogen and a mix of gases around that. It has only $1/10^{th}$ of the proportion of gas found in the Sun. It could never have nuclear fusion in its core, even if it were big enough to be a star, because its core isn't mostly hydrogen.

Modeling the Solar System to Scale

There are **two things to model** about the solar system, the **spacing of the planets' orbits** and the **diameters of the planets and the Sun**. To get both of these into one scale model, you need at least a kilometer and a half, with Jupiter at a diameter of 35 mm and Pluto at 0.5 mm. You may wish to model orbits and diameters separately, or else just model the first few planets with both parameters to scale.

Whichever way you decide to do it, there is great help for you at this website from the Exploratorium: http://www.exploratorium.edu/ronh/solar_system/index.html. It calculates the size and mean orbital distance of the planets when you enter a measurement for the Sun. If you set the size of the Sun at 1.4 mm in diameter, you will get distance measurements for the planet's orbits that you can use in a classroom. (See the table below). If you want to make scale models of the planets themselves, set the size of the Sun at 1500 mm or more. The table below uses a 3000 mm Sun. Lastly, remember the AU (Astronomical Unit). It can make the comparison of planet orbits simple enough to be meaningful.

I've given all the decimal places on the figures, assuming it is easier to round off than to find more precise measurements. You may wish to round these figures off before giving them to beginning students. More advanced students can simplify the numbers for themselves as needed.

Students can use cash register tape to model the distance to the planets' orbits. It takes about 6 meters of tape per model. First they draw a tiny circle (1.4 mm diameter) at one end to represent the Sun. Then they mark a line at the mean orbital distance from the Sun and label the planet at that location. None of the planets are big enough to see at this scale. You will need to provide a metric ruler for the inner planets and a meter stick or metric tape measure for the outer ones. Remind students that 0.001 meter is a millimeter and 0.01 meter is a centimeter.

Name of body	Diameter (in mm) when the Sun is 3000 mm in diameter	Distance (in meters) from Sun to orbit when the Sun is 1.4 mm in diameter	Mean orbital distance from Sun in AU
Sun	3000.0	0	0
Mercury	10.4	0.058 (5.8 cm)	0.39
Venus	26.0	0.108 (10.8 cm)	0.72
Earth	27.4	0.150 (15 cm)	1 (by definition)
Mars	14.5	0.229 (22.9 cm)	1.52
Jupiter	300.7	0.782 (78.2 cm)	5.20
Saturn	250.9	1.435	9.54
Uranus	101.1	2.887	19.18
Neptune	97.9	4.526	30.06
Pluto	4.9	5.947	39.44

Hint: Set your compass at half the diameter to draw the circles for the planet diameter model. You will need 11X17 paper or other large-sized sheets for Jupiter and Saturn. Try marking just a portion of the Sun's outline on a piece of wide banner paper. You can use a string that is 1.5 meters long for a compass and place the center off the paper. You'll just see the curve of the Sun's surface, but it will fit in the room.

Take a look at your models. Wow! Did you ever realize how powerful gravity is and how much space there is in space? Your models will give you a new view of solar system diagrams.

Units for modeling the solar system – the Astronomical Unit

It takes a BIG yardstick to measure our solar system. The **Astronomical Unit (AU)** is the easiest unit to grasp for models of the planets' orbits and the location of the Kuiper Belt and Oort Cloud. An AU is the average distance of the Earth from the Sun, approximately 150 million kilometers (93 million miles). The Kuiper Belt extends from just beyond Pluto to 100 AU. The Oort Cloud lies in a zone that is 50,000 to 100,000 AU from the Sun.
One AU is the distance: a passenger jet can travel in 20 years; a space probe flying fast enough to escape Earth's gravity (That's faster than the Space Shuttle!) travels in 5 months; light travels in 8 minutes.

Planet terminology

Eccentricity – a measure of the "flatness" of an ellipse. For planets, it is a measure of how different their orbits are from a circle. Circular orbits have an eccentricity of zero. Very elongated, flattened orbits have an eccentricity of nearly one. Eccentricity = distance between the two foci divided by the length of the major axis of the ellipse.

Tilt– the number of degrees that the axis of a planet differs from vertical

Orbital inclination – the number of degrees that the orbital plane of a planet differs from the plane of the ecliptic

Perihelion – (per-eh-HEEL-yen) the point in a planet's orbit that is closest to the Sun, from Gk. *peri*-, near + *helios*, Sun)

Aphelion – (ah-FEEL-yen) the point in a planet's orbit that is farthest from the Sun, from Gk. *apo*-, away from + *helios*, Sun) Note: for satellites of the Earth, including the Moon, the corresponding terms are apogee and perigee.

Drawing Planets' Orbits – Kepler's 1st Law states that planets have elliptical orbits

Your students will understand planets' orbits better if they draw ellipses and label the location of the Sun, the perihelion, and the aphelion. You will need the following for this exercise: a cork board or a stack of cardboard, unlined paper, several colored pencils, two push pins, a metric ruler, and a loop of non-stretchy string. Make the loop by tying the ends of a 25 cm length of the string.

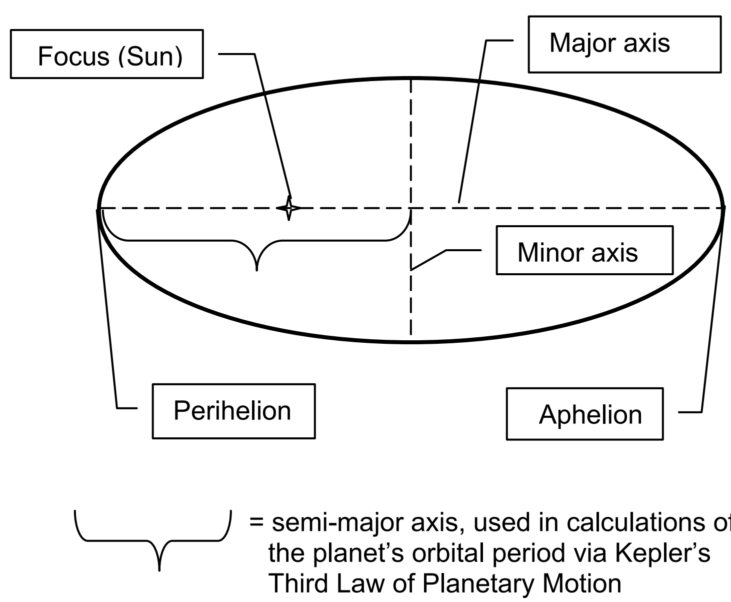
- Mount a piece of paper on the corkboard. Use tape or more pins to anchor it in place.
- Draw a line across the middle of the paper. The major axes of your ellipses will lie along this line.
- Draw a small mark perpendicular to the line about halfway across it. Label this position "Sun". Stick one push pin into the cross mark. Make sure the pin is pushed down far enough that it won't shift during the drawing.
- Place the loop of string over the push pin and insert one of the pencils in it. Stretch the string taut and draw a circle.
- Add the second push pin about 1 cm from the first, with its point through the line. Loop the string around both pins, and use a second color of pencil to draw the first ellipse.
- Keep moving the second push pin away from the "Sun", about 1.5 cm each time, keeping it on the line. Draw the ellipse at each position with a different colored pencil.

The drawing you make will have a circle with several ellipses nested inside. The figures will all share a point at one side. You will be able to measure the length of the major axis of each ellipse and the distance between the two pins, which are the foci. From this, advanced students can calculate the eccentricity of their ellipses. Eccentricity equals the distance between foci divided by the length of the major axis.

You will see that the planets have orbits that are very nearly circles. Your first ellipse should have an eccentricity of about 0.04, which is near that of Uranus and Jupiter, but more than the eccentricity of Earth, Venus, and Neptune. Your last ellipse will be nearly the shape of a comet's orbit. Comets usually have eccentricities near 1.

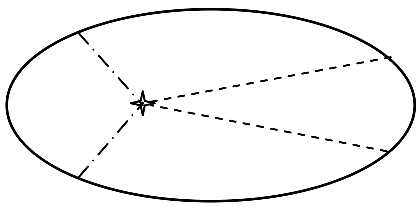
Name	Perihelion (AU)	Aphelion (AU)	Eccen-tricity
Mercury	0.31	0.47	0.206
Venus	0.72	0.73	0.007
Earth	0.98	1.02	0.017
Mars	1.38	1.67	0.093
Jupiter	4.95	5.45	0.048
Saturn	9.01	10.07	0.054
Uranus	18.28	20.09	0.047
Neptune	29.80	30.32	0.009
Pluto	29.6	49.3	0.249

Parts of an elliptical orbit



Advanced students may wish to work with Kepler's Second Law of Planetary Motion.
It states that an imaginary line connecting a planet with the Sun sweeps out equal areas over the same time period. This means that planets travel faster when they are near the Sun and slower when they are near their aphelion. Here's an exercise to see what this is like.

1. Using a piece of graph paper with 4 lines per inch, draw a line for the major axis of your ellipse. Use foci about 3.75 inches apart and a loop made from 30 cm of string. Draw the ellipse. This represents the orbit of a hypothetical planet. Designate one focus as the Sun.
2. Draw lines from two points equidistant on either side of the planet's aphelion to the Sun. This forms a wedge that shows the area the planet would "sweep out" as it rounds the far end of its orbit. Determine the area of the wedge. (Hint: divide it into a triangle, calculate its area, estimate the rest.)
3. Estimate what you think will be an equal area on the perihelion end of the orbit and mark this wedge on the ellipse. Count the squares or divide the area into triangles and estimate the area. Are your wedges equal in area or do you have to enlarge or reduce the perihelion wedge to equalize the areas?
4. When you have equal wedges, mark the two points on the orbit where each wedge starts and ends. The planet would travel these portions of its orbit in the same amount of time.



First lines form aphelion wedge

Second lines form perihelion wedge

The planet travels between the two points where the lines intersect its orbit in the same amount of time, if the areas of the wedges are equal. No wonder comets take so long to return to the Sun!

What does this mean for Earth? Look in an Old Farmer's Almanac for a column that is labeled "Sun Fast". It shows the difference between sundial time and clock time. From this you can see that the Earth is a bit faster in some of its orbit (moves beyond solar noon in 24 hrs.) and a bit slower in others.

What's the ecliptic?
The ecliptic is an imaginary plane in which the Earth orbits. The axis of the Earth is tilted 23.5 degrees from perpendicular to the ecliptic, which is why we have seasons. On a globe, intersection of the ecliptic plane and the Earth is sometimes shown as a line with dates beside it. The date is the day of the year when sunlight is strikes perpendicular to the Earth at the latitude where the date is given. From the Earth, we see the constellations of the zodiac in the plane of the ecliptic. The Sun, Moon, and the planets are found in this region as well. If you are looking for planets, look along the ecliptic.

A tour of the planets with comments on their formation

The planets are a varied lot. Each of them has its own story. Here are some of their special characteristics and hypotheses about how they came to be.

Mercury has a huge iron core, about ¾ of its diameter in size. This is proportionally larger than it should be even for Mercury's inner orbit. Astronomers think that a large object hit Mercury and knocked much of its outer rocky layer off. The Sun and Venus probably pulled in the loose material. Mercury's orbit was changed, so that it is more eccentric and more inclined.

Venus has the only retrograde rotation (in the opposite direction to the other planets). It also rotates very slowly, taking 243 days per revolution, longer than its year of 225 days. We don't know what caused Venus's unique properties, but possibly a head-on collision with a large body changed its rotation.

Earth is the densest planet. It alone has oceans of water. We are not sure of the origin of their water, since there was little water in the inner solar system when Earth formed. Some was probably stuck to minerals within the Earth, and was brought to the surface by volcanic eruptions. Some probably came from impacts of icy planetesimals and comets from the outer solar system. For a discussion of current ideas on Earth's water, see *Science News Magazine*, March 23, 2002, pp. 184-186.

Earth's moon probably originated from the glancing impact of a Mar-sized body with the early Earth. Material thrown from Earth's surface joined the mantle of the colliding body and coalesced into the Moon. The core of the body fell into the Earth and joined to its core. This explains the lower density of the Moon, its relatively small metallic core, and the composition of its crust.

Mars has two tiny captured planetesimals for its moons, which are named Phobos (Fear) and Deimos (Panic). Phobos is slowly spiraling into Mars and is estimated to hit the planet's surface within 40 million years. Mars may have had a dense atmosphere, much like Earth's early in its history, which would have allowed its surface temperatures to be high enough for water to be liquid. Its small gravity couldn't hold onto its atmosphere and it cooled considerably once the atmosphere was lost.

The **asteroid belt** has less than 1/10 of the Moon's mass, and it is spread from 2.1-3.3 AU from the Sun, so it is really quite sparse. The asteroids are left-over planetesimals, irregular, cratered rocky lumps. One, Ida, even has a tiny moon that is only about 1½ km in diameter. Jupiter's large gravity probably removed much of the material that was originally in this orbit and distorted the orbits of the rest.

Jupiter likely had a dusty disk around it when it formed. Its four Galilean moons are like a miniature solar system. They move in nearly circular, prograde (same direction as the planets) orbits. Their densities decrease along with distance from the planet. Space probe measurements indicate that the inner two have rocky cores and the outer two have more ices mixed in with their rock. Closer in there are four small moons in prograde, circular orbits. A group of small moons with prograde, but highly eccentric, inclined orbits, moves far beyond the Galilean moons. These are likely captured asteroids. Farther away still are a group of small moons that have retrograde, highly eccentric, inclined orbits and these are almost certainly captured asteroids. NOTE: you are likely to find many different figures on the number of moons of the giant planets. More tiny ones keep being discovered. Don't worry too much about the total number. Try describing the major moons and the types of minor moons without a total count.

Saturn, with its beautiful rings, is the least dense planet. It formed slightly after Jupiter, and ran out of material before it got as big. Its rings are ice and ice-coated rock. They are so thin that a good model of their cross section would be a film of plastic wrap spread over a football field. They are thought to have formed when moons got too close to Saturn, and the tidal pull of the planet's gravity broke them apart.

Uranus formed after much of the gas was gone from the solar nebula, and so has a smaller proportion of gas than Saturn. It is an ice giant, with a rocky and icy core that is covered with a shell of water, methane, and ammonia ice. The outer icy layer is methane, which gives it its blue-green color. Its axis is tilted all the way over on its side, probably from the impact of a protoplanet about the size of the Earth. Its moons orbit around its equator, in a plane perpendicular to the plane of the solar system.

Neptune is the farthest planet that accreted near its present orbit. It is deep blue, from the methane mixed with its hydrogen-helium atmosphere. Triton, its large moon, is bigger than Pluto and it has a retrograde orbit. This moon is likely a captured planetesimal from the Kuiper Belt.

Pluto is either the last planet or the first object in the Kuiper Belt. Its icy moon, Charon (KARE-on), is over half its diameter and 1/7 its mass, making them more like twin planets. Charon has a strange orbit, about 90° to the plane of the solar system. Perhaps Pluto captured Charon after a collision or near miss.

What must theories of solar system formation explain?

Any theory of the solar system's formation must explain its current characteristics. Here are some of those characteristics and our best explanation of them.

All of the planets **orbit in the same direction** as the Sun rotates. Explanation: they formed from a cloud that was spinning in the direction they now orbit.

All of the planets except Pluto **orbit in nearly the same plane**. Explanation: the planets formed from a disk of material. It is very unlikely that the Sun could capture 8 planets and have them all in the same plane.

The **inner planets have metallic cores** and rocky exteriors, but little hydrogen or helium. The **outer planets have** proportionally smaller solid cores and with **large exterior layers of gases or ice**. Explanation: the Sun's heat and radiation removed most of the gas and lighter substances from the inner solar system.

The **planets have denser cores and lighter exteriors**. Explanation: The energy of planetesimal collisions heated up the young planets. Later, radioactive decay continued to heat the center of the planets. The two processes melted the planets' cores. Gravity pulled the heaver materials to the center. Lighter materials floated upward. A planet or other body is said to be differentiated if it has a denser core and less dense outer layers.

Meteorites can include tiny **diamonds**, which only form under extreme heat and pressure, and **silicon carbide**, which forms in outer layers of red giant stars. Explanation: Some materials (in addition to the heavier chemical elements) in the solar nebula formed during the death of a giant star and in the pressure wave of its supernova.

Resources for solar system study

Books for children – See Dewey Decimal numbers 520, 523.

1998. ***The Universe***. Time-Life Student Library. ISBN 0-7835-1354-2. Illustrates the beginning of the solar system and gives data on planets. UE-MS.

Branley, Franklyn M. 1996. ***The Sun and the Solar System*** (Secrets of Space). Twenty-First Century Books. ISBN 0-8050-4475-2. This has basic information about the formation of the planets and their characteristics. LE-UE

Brimmer, Larry Dane. 1999. ***Jupiter***. A True Book. Children's Press. ISBN 0-516-21153-6. This is a well-done introduction to the planet, with a fact page and Internet resources. The same author has books on the other planets as well. LE-younger UE

Dickinson, Terence. 1995. ***Other Worlds: A Beginner's Guide to Planets and Moons***. Firefly Books. ISBN 1-895565-71-5. The astronomer-author gives clear, accurate information and excellent diagrams. This covers moons. UE-MS

Graun, Ken. 2001. ***Our Earth and the Solar System***. 21st Century Astronomy Series. Ken Press. ISBN 1-928771-02-5. An excellent, accurate introduction to the solar system. It shows the whole Sun + planets to scale. Recommended. LE-UE

Kerrod, Robin. 2000. ***The Solar System***. Lerner Publications Co. ISBN 0-8225-3903-9. This has the story of the solar system's formation. It shows an overview of the solar system with the rotational direction indicated. UE

Levy, David H. 1996. ***Stars and Planets***. The Nature Company Discoveries Library. Time-Life Books. ISBN 0-8094-9246-6. Nice illustrations, basic information for LE-UE.

Mitton, Simon and Jacqueline. 1995. ***The Young Oxford Book of Astronomy***. Oxford University Press. ISBN 0-19-521445-5. This includes a good diagram of the solar system and a chapter on planet's orbits. It is a great reference for UE-MS.

Rau, Dana Meachen. 2001. ***The Solar System*** (Simply Science). Compass Point Books. ISBN 0-7565-0036-2. A well-done and current introduction to the solar system for LE.

Scagell, Robin. 1996. ***Space Explained: A Beginner's Guide to the Universe***. Henry Holt and Company. ISBN 0-8050-4872-3. A basic overview of the solar system's formation and information on each planet. LE-UE

Wiese, Jim. 1997. ***Cosmic Science: Over 40 …Activities for Kids***. John Wiley & Sons, Inc. ISBN 0-471-15852-6. This has demonstrations that use common materials. Many are useful for solar system studies. LE-MS

Books for reference and further study

Booth, Nicholas. 1995. ***Exploring the Solar System***. Cambridge University Press. ISBN 0-521-58005-6. This has a good summary of the solar system's formation for MS-adult level. The sections on each planet detail what we know, important questions that remain, and extensive information on space probes.

Chaisson, Eric and Steve McMillan. 2001. ***Astronomy: A Beginner's Guide to the Universe***. 3rd ed. Prentice Hall. ISBN 0-13-087307-1. An introductory textbook for non-science majors, it offers clear information and comes with a CD-ROM version.

Croswell, Ken. 1999. ***Magnificent Universe***. Simon & Schuster. ISBN 0-684-84594-6. This large hardback provides easy-to-read text and wonderful illustrations (good for all levels). It's one of my favorites. MS-Adult

McNab, David and James Younger. 1999. ***The Planets***. Yale University Press. ISBN 0-300-08044-1. This deals primarily with space probes and our acquisition of knowledge about the planets. It is based on a BBC series.

Moore, Patrick. 2001. ***Patrick Moore on the Moon***. Cassell & Co. ISBN 0-304-35469-4. This highly readable book has a chapter on the origin of the solar system and Earth's moon.

Spence, Pam. 1998. ***The Universe Revealed***. ISBN 0-52164-239-6. This has a good section on solar system origin.

Tyson, Neil deGrasse, Charles Liu, and Robert Irion. 2000. ***One Universe: At Home in the Cosmos***. Joseph Henry Press. ISBN 0-309-06488-0. This has a good diagram of Jupiter and the orbits of its moons. HS-Adult

Internet sites:

Students for the Exploration and Development of Space (SEDS) produces a comprehensive site called "Nine Planets". http://www.seds.org/nineplanets/nineplanets/intro.html

Origin of the solar system from the Nine Planets: http://www.seds.org/nineplanets/nineplanets/origin.html

Build a model of the solar system – this site calculates the scale: http://www.exploratorium.edu/ronh/solar_system/

Calculate your weight on other planets and stars: http://www.exploratorium.edu/ronh/weight/index.html

Planetary Science Institute page on solar system origins: http://www.psi.edu/projects/planets/planets.html#INTRO

This simulator shows planetary motion: http://www.humnet.ucla.edu/humnet/french/faculty/gans/java/SolarApplet.html

This is a site where you can order a good solar system poster. It lists things about Earth that are just right for life. http://www.arn.org/arnproducts/posters/p103.htm

For printable pictures of planets and other solar system objects see: http://spaceplace.nasa.gov/teachers_ss_images.htm

You can print and assemble your own globes for Mars, Venus, Europa, and Ganymede from this site. http://astrogeology.usgs.gov/Projects/MapsAndGlobes/

See the GEMS (Great Explorations in Math and Science) site for activities in astronomy (including Moons of Jupiter and The Real Reasons for the Seasons) at: http://128.32.86.250/gems/gemsguidestopic.html

PASS (Planetarium Activities for Student Success) has a listing of reports on the moons of the solar system. http://www.lhs.berkeley.edu/PASS/PASSv7updates.html