Planet Data Table

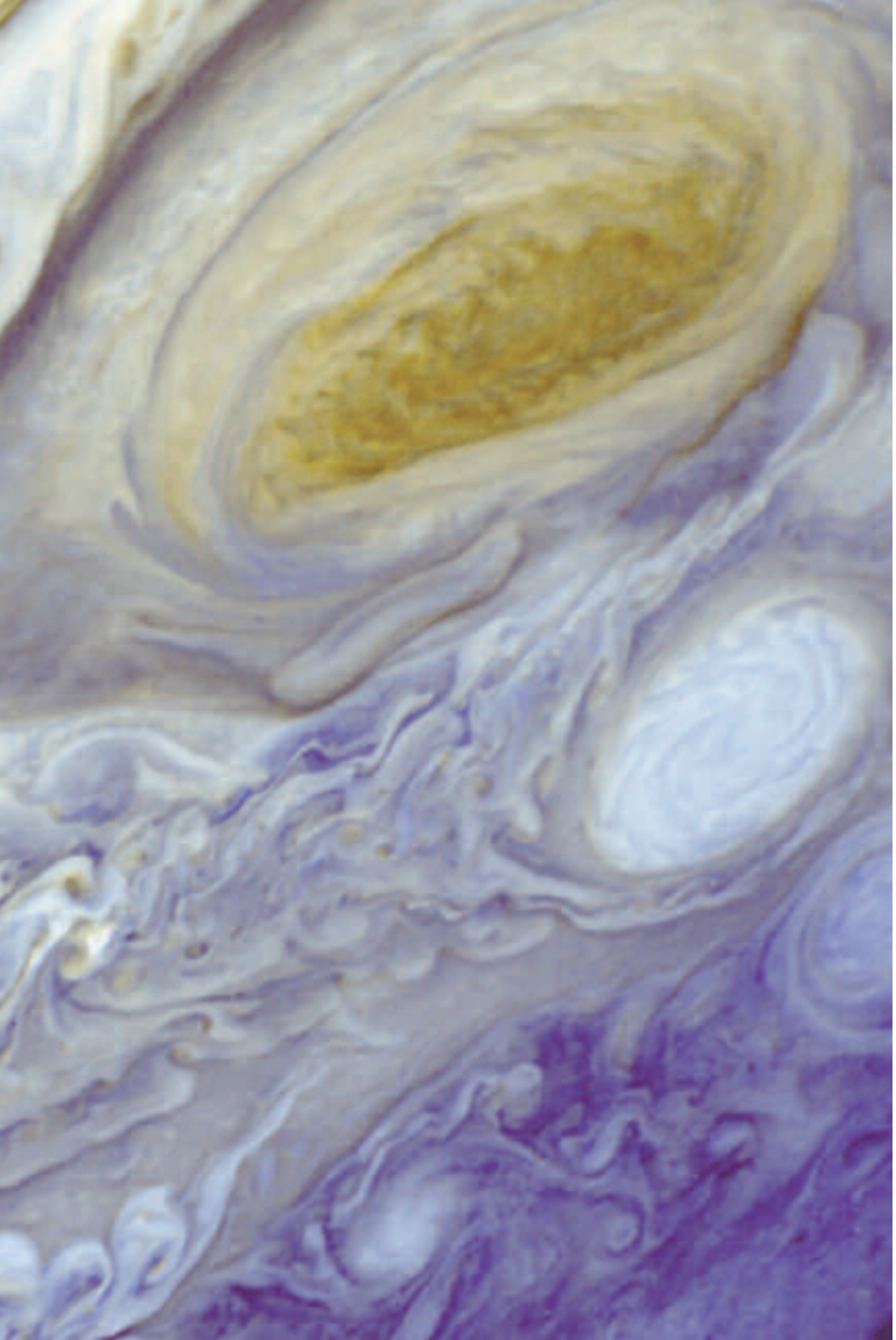
	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune
diameter (Earth=1)	0.382	0.949	1	0.532	11.209	9.44	4.007	3.883
diameter (km)	4,878	12,104	12,756	6,787	142,800	120,000	51,118	49,528
mass (Earth=1)	0.055	0.815	1	0.107	318	95	15	17
mean distance from Sun (AU)	0.39	0.72	1	1.52	5.20	9.54	19.18	30.06
orbital period (Earth years)	0.24	0.62	1	1.88	11.86	29.46	84.01	164.8
orbital eccentricity	0.2056	0.0068	0.0167	0.0934	0.0483	0.0560	0.0461	0.0097
mean orbital velocity (km/sec)	47.89	35.03	29.79	24.13	13.06	9.64	6.81	5.43
rotation period (in Earth days)	58.65	-243*	1	1.03	0.41	0.44	-0.72*	0.72
inclination of axis (degrees)	0.0	177.4	23.45	23.98	3.08	26.73	97.92	28.8
mean temperature at surface (C)	-180 to 430	465	-89 to 58	-82 to 0	-150	-170	-200	-210
gravity at equator (Earth=1)	0.38	0.9	1	0.38	2.64	0.93	0.89	1.12
escape velocity (km/sec)	4.25	10.36	11.18	5.02	59.54	35.49	21.29	23.71
mean density (water=1)	5.43	5.25	5.52	3.93	1.33	0.71	1.24	1.67
atmospheric composition	none	CO_2	N_2 + O_2	CO_2	H_2+He	H_2+He	H_2+He	H_2+He
number of moons	0	0	1	2	63	62	27	13
rings?	no	no	no	no	yes	yes	yes	yes

Dwarf Planets

	Ceres	Pluto	Haumea	Makemake	Eris
diameter (Earth=1)	0.076	0.180	0.110 (average)	0.102-0.149	0.188-0.235
diameter (km)	974.6	2,300	1,960 x 1,518 x 996 (ellipsoid)	1,300-1,900	2,400-3,000
mass (Earth=1)	0.00016	0.002	0.00070	0.00067	0.0028
mean distance from Sun (AU)	2.76596	39.44	43.335	45.791	67.6681
orbital period (Earth years)	4.599	247.7	285.4	309.88	557
orbital eccentricity	0.07976	0.2482	0.18874	0.159	0.44177
mean orbital velocity (km/sec)	17.882	4.74	4.484	4.419	3.436
rotation period (in Earth days)	0.378	-6.38*	0.163	?	> 8 hrs ?
inclination of axis (degrees)	3	122	?	?	?
mean temperature at surface (°C)	-106	-220	-223	-240	-230
gravity at equator (Earth=1)	0.028	0.06	0.045	0.051	0.082
escape velocity (km/sec)	0.51	1.27	0.84	0.8	1.31
mean density (water=1)	2.077	2.03	2.6-3.3	2	1.18-2.31
atmospheric composition	none	CH_4	none?	maybe CH_4	maybe CH_4
number of moons	0	3	2	0	1
rings?	no	no	no	no	no

* Negative values of rotation period indicate that the planet rotates in the direction opposite to that in which it orbits the Sun. This is called retrograde rotation.

The eccentricity (e) is a number which measures how elliptical orbits are. If e=0, the orbit is a circle. All the planets have eccentricities close to 0, so they must have orbits which are nearly circular.



Solar System Physical Data

Physical Properties of Solar System Members

	Equatorial Diameter		Mass[1] Earth=1	Density[2] H_2O=1	Gravity[3] Earth=1	Albedo[4]
SUN	865,278 miles	1,392,530 km	332,946	1.41	27.9	n/a
MERCURY	3,032 miles	4,879 km	0.055	5.43	0.38	11%
VENUS	7,521 miles	12,104 km	0.815	5.25	0.90	65%
EARTH	7,926 miles	12,756 km	1	5.52	1.00	37%
MARS	4,228 miles	6,805 km	0.107	3.95	0.38	15%
JUPITER	88,844 miles	142,980 km	317.8	1.33	2.53	52%
SATURN	74,900 miles[5]	120,540 km[5]	95.2	0.69	1.06	47%
URANUS	31,764 miles	51,120 km	14.5	1.29	0.90	51%
NEPTUNE	30,777 miles	49,530 km	17.2	1.64	1.14	41%
PLUTO	1,433 miles	2,306 km	0.0025	2.03	0.08	30%

[1]Earth's mass is 1.32 x 10^{25} pounds (5.97 x 10^{24} kg). [2]Density per unit volume as compared to water. For comparsion, the density of alumium is 2.7 and iron is 7.7. [3]Gravity at equator. [4]Albedo is the amount of sunlight reflected by the Planet. [5]Saturn without rings. Visible rings are approximately 170,000 miles (273,600 km) in diameter.

	Rotational Period (Planet's Day)	Escape Velocity[1]		Oblateness[2]	Inclination to Orbit[3]
SUN	25 to 35 days[4]	384 miles/s	617.5 km/s	0	7.2∞[5]
MERCURY	58.7 days	2.6 miles/s	4.2 km/s	0	0.0∞
VENUS	243.0 days	6.5 miles/s	10.4 km/s	0	177.4∞
EARTH	1 day	6.96 miles/s	11.2 km/s	0.34%	23.4∞
MARS	24.62 hours	3.1 miles/s	5.0 km/s	0.74%	25.2∞
JUPITER	9.84 hours	37 miles/s	59.5 km/s	6.5%	3.1∞
SATURN	10.23 hours	22.1 miles/s	35.5 km/s	9.8%	25.3∞
URANUS	17.9 hours	13.2 miles/s	21.3 km/s	2.3%	97.9∞
NEPTUNE	19.2 hours	14.6 miles/s	23.5 km/s	1.7%	28.3∞
PLUTO	6.4 days	0.8 miles/s	1.3 km/s	unknown	123∞

[1]At equator. [2]Bulging at the equator caused by rotation of Planet on axis. Percentage indicates the amount of extra equatorial diameter as compared to the polar diameter. [3]Inclination of Planet's rotational axis to Planet's orbit around Sun. [4]Sun rotates about 10 days faster at its equator than at its poles. [5]Inclination of Sun's rotational axis to Earth's orbit.

Facing page. *A closeup of the Great Red Spot and surrounding clouds on Jupiter. The Great Red Spot is at the top of this picture and is physically larger than Earth. This hurricane-type vortex spans 25,000 miles (40,000 kilometers).*

Solar System Orbital Data

Orbital Properties of Solar System Members

	Average Distance from Sun[1]			Eccentricity[3]
	Astronomical Units (AU)[2]	*Miles*	*Kilometers*	
MERCURY	0.387	35,980,000	57,910,000	2.2%
VENUS	0.723	67,230,000	108,200,000	0.003%
EARTH	1.000	92,955,800	149,597,870	0.015%
MARS	1.524	141,640,000	227,940,000	0.44%
JUPITER	5.203	483,630,000	778,330,000	0.16%
SATURN	9.539	886,680,000	1,426,980,000	0.16%
URANUS	19.191	1,783,950,000	2,870,990,000	0.12%
NEPTUNE	30.061	2,794,350,000	4,497,070,000	0.004%
PLUTO	39.529	3,674,490,000	5,913,520,000	3.3%

[1]The Planets' orbits around the Sun are ellipses, not circles. Thus, they have a closest and farthest distance to the Sun. [2]One astronomical unit is the average distance of the Earth to the Sun, 92,955,800 miles. [3]Eccentricity is normally expressed as a decimal and represents the elongation of a Planet's elliptical orbit. Ellipses have both a major (longer) and minor (shorter) axis. For clarity, I have expressed eccentricity as a percentage indicating how much longer the major axis is as compared to the minor axis. Although the Planets' orbits are ellipses, all nine have orbits that are very close to circles. Seven of the Planets have eccentricities less than 1%.

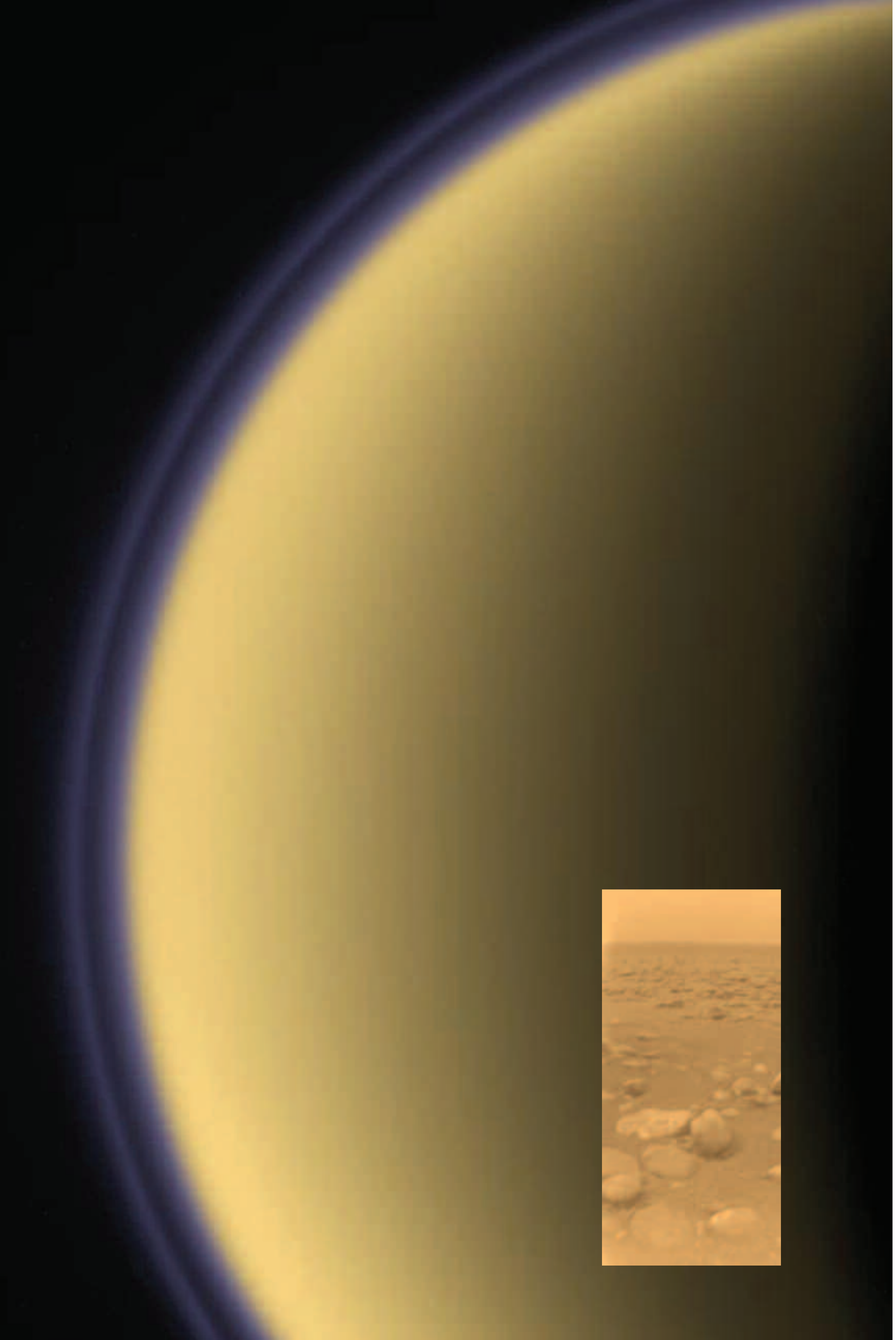
	Revolution Around Sun (Planet's Year)	Average Orbital Velocity		Inclination of Orbit to Earth's Orbit
MERCURY	87.97 days	29.76 miles/s	47.89 km/s	7.00∞
VENUS	224.70 days	21.77 miles/s	35.03 km/s	3.39∞
EARTH	365.26 days	18.51 miles/s	29.79 km/s	0.00∞
MARS	686.98 days	14.99 miles/s	24.13 km/s	1.85∞
JUPITER	11.86 years	8.12 miles/s	13.06 km/s	1.31∞
SATURN	29.42 years	5.99 miles/s	9.64 km/s	2.49∞
URANUS	83.75 years	4.23 miles/s	6.81 km/s	0.77∞
NEPTUNE	163.73 years	3.37 miles/s	5.43 km/s	1.77∞
PLUTO	248.03 years	2.95 miles/s	4.74 km/s	17.15∞

Solar System Atmospheres

Atmospheres of Solar System Members

	Description of Atmosphere	Temperature
MERCURY	No atmosphere[1]	800∞ F Day (427∞ C) –300∞ F Night (–184∞ C)
VENUS	96% Carbon Dioxide, 3.5% Nitrogen *Atmospheric Pressure: 90 bars*	Averages 900∞ F (482∞ C)
EARTH	77% Nitrogen, 21% Oxygen, 1% Water, 1% Argon *Atmospheric Pressure: 1 bar*	Averages 59∞ F (15∞ C) Highest 136∞ F (58∞ C) Lowest –129∞ F (–89∞ C)
MARS[2]	95% Carbon Dioxide, 2.7% Nitrogen, 1.6% Argon, 0.2% Oxygen *Atmospheric Pressure: 0.007 bar*	Averages –67∞ F (–55∞ C) High 80∞ F (27∞ C) Low –207∞ F (–133∞ C)
JUPITER[3]	90% Hydrogen Gas, 10% Helium Gas	–243∞ F (–153∞ C) just below cloudtops
SATURN[3]	97% Hydrogen Gas, 3% Helium Gas	–301∞ F (–185∞ C) just below cloudtops
URANUS[3]	83% Hydrogen Gas, 15% Helium Gas 2% Methane Gas	–323∞ F (–197∞ C) just below cloudtops
NEPTUNE[3]	74% Hydrogen Gas, 25% Helium Gas 1% Methane Gas	–373∞ F (–225∞ C) just below cloudtops
PLUTO	100% Methane Gas? Some Nitrogen? *Extremely low atmospheric pressure*	–419∞ F (–233∞ C)

[1]Mercury has no atmosphere in the conventional sense, however, there are trace quantities of Helium, Sodium and Oxygen and an atmospheric pressure of 10^{-15} bars. [2]Since the atmospheric pressure on Mars is low, temperature can decrease by as much as 18 F∞ (10 C∞) from the surface to a height of just 3 feet (1 meter). [3]Jupiter, Saturn, Uranus and Neptune are Gas Giants and thus do not have, in the conventional sense, a surface below the clouds. Therefore, they do not have a reference point from which to measure a standard atmospheric pressure.



Solar System Moons

Major Moons of the Planets[1]

	Moon Name	Average Distance from Planet[2]	Revolution Period[3]	Diameter	Visual Magnitude[4]
MERCURY	*Mercury has no moons*				
VENUS	*Venus has no moons*				
EARTH	*Earth has 1 moon*				
	Moon	238,920 miles 384,500 km	27.3 days	2,160 miles 3,476 km	–12.7
MARS	*Mars has 2 moons*				
	Phobos	5,830 miles 9,380 km	7.7 hours	17 x 13 miles 27 x 21 km	11.6
	Deimos	14,580 miles 23,460 km	1.3 days	10 x 8 miles 16 x 13 km	12.7
JUPITER	*Jupiter has 63 known moons[5] (This count will most likely rise)*				
	Io	262,000 miles 421,600 km	1.77 days	2,255 miles 3,629 km	5.0
	Europa	416,900 miles 670,900 km	3.55 days	1,950 miles 3,138 km	5.3
	Ganymede	664,900 miles 1,070,000 km	7.16 days	3,270 miles 5,261 km	4.6
	Callisto	1,171,000 miles 1,885,000 km	16.69 days	2,980 miles 4,800 km	5.6
SATURN	*Saturn has 56 known moons[6] (This count will most likely rise)*				
	Mimas	116,200 miles 187,000 km	0.9 days	242 miles 390 km	12.5
	Enceladus	147,900 miles 238,000 km	1.4 days	311 miles 500 km	11.8
	Tethys	183,300 miles 295,000 km	1.9 days	659 miles 1,060 km	10.3
	Dione	234,900 miles 378,000 km	2.7 days	699 miles 1,120 km	10.4
	Rhea	326,800 miles 526,000 km	4.5 days	951 miles 1,530 km	9.7
	Titan	758,100 miles 1,221,000 km	15.9 days	3,200 miles 5,150 km	8.4
	Iapetus	2,212,700 miles 3,561,000 km	79.3 days	907 miles 1,460 km	11.0

Facing page. *Titan, Saturn's largest moon has a nitrogen/methane atmosphere. The inset shows Titan's surface as imaged by the Huygen's probe in 2005.*

Solar System Moons

Major Moons of the Planets[1]

	Moon Name	Average Distance from Planet[2]	Revolution Period[3]	Diameter	Visual Magnitude[4]
URANUS	*Uranus has 27 known moons[7] (This count will most likely rise)*				
	Ariel	118,600 miles 190,900 km	2.5 days	721 miles 1,160 km	14.0
	Umbriel	165,300 miles 266,000 km	4.1 days	739 miles 1,190 km	14.9
	Titania	271,100 miles 436,300 km	8.7 days	1,000 miles 1,610 km	13.9
	Oberon	362,500 miles 583,400 km	13.5 days	963 miles 1,550 km	14.1
NEPTUNE	*Neptune has 13 known moons[8] (This count will most likely rise)*				
	Triton	220,000 miles 354,000 km	5.9 days	1,678 miles 2,700 km	13.6
	Nereid[1]	3,423,800 miles 5,510,000 km	365.2 days	211 miles 340 km	19.7
PLUTO[10]	*Pluto has 3 known moons[9] (This count could rise)*				
	Charon	11,900 miles 19,100 km	6.4 days	746 miles 1,200 km	17

NOTE: All moon data and counts are current as of June, 2006.
[1]Data for only the major moons are provided because the lesser moons are small and require large telescopes and photographic means to identify. A typical example of these lesser moons is Nereid, Neptune's second largest moon, which is listed in this table. [2]Distance measured from center of Planet. [3]Orbit around Planet. [4]Visual magnitude from Earth at Planet's closest approach. [5]The named moons of **JUPITER** are (from innermost to outermost): Metis, Adrastea, Amalthea, Thebe, Io, Europa, Ganymede, Callisto, Themisto, Leda, Himalia, Lysithea, Elara, Carpo, Euporie, Thelxinoe, Euanthe, Helike, Orthosie, Iocaste, Ananke, Praxidike, Harpalyke, Hermippe, Orthosie, Thyone, Mneme, Aitne, Kale, Taygete, Chaldene, Erinome, Aoede, Kallichore, Kalyke, Eurydome, Pasithee, Cyllene, Eukelade, Hegemone, Arche, Isonoe, Pasipaë, Sinope, Sponde, Autonoe, Callirrhoe and Megaclite. [6]The named moons of **SATURN** are (from innermost to outermost): Pan, Daphnis, Atlas, Prometheus, Pandora, Epimetheus & Janus, Mimas, Methone, Pallene, Enceladus, Tethys & Telesto & Calypso, Dione & Polydeuces & Helene, Rhea, Titan, Hyperion, Iapetus, Kiviuq, Ijiraq, Phoebe, Paaliaq, Skathi, Albiorix, Erriapo, Siarnaq, Tarvos, Mundilfari, Narvi, Suttungr, Thrymr and Ymir. [7]The named moons of **URANUS** are (from innermost to outermost): Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Rosalind, Cupid, Belinda, Perdita, Puck, Mab, Miranda, Ariel, Umbriel, Titania, Oberon, Francisco, Caliban, Stephano, Trinculo, Sycorax, Margaret, Prospero, Setebos and Ferdinand. [8]The named moons of **NEPTUNE** are (from innermost to outermost): Naiad, Thalassa, Despina, Galatea, Larissa, Proteus, Triton, Nereid and Psamathe. [9]The named moons of **PLUTO** are (from innermost to outermost): Charon, Nix and Hydra.
[10]See page 155 for a discussion about Pluto's planetary status.

Solar System Comparison

QUICK COMPARISON of Solar System Members

	Distance from Sun[1] Earth=1	Light Time[2]	Diameter[3] Earth=1	Mass[4] Earth=1	Volume[5] Earth=1
SUN	n/a	n/a	109	333,000	1,300,000
MERCURY	0.4	3.2 minutes	0.4	0.06	0.06
VENUS	0.7	6 minutes	0.95	0.8	0.9
EARTH	1	8.3 minutes	1	1	1
MARS	1.5	12.7 minutes	0.5	0.1	0.15
JUPITER	5.2	43.3 minutes	11.2	318	1,326
SATURN	9.5	1h 19min	9.5	95	771
URANUS	19	2h 40min	4	15	63
NEPTUNE	30	4h 10min	3.8	17	58
PLUTO	39.5	5h 29min	0.2	0.003	0.006

[1]The average distance from the Earth to the Sun is 92,955,800 miles (149,597,870 km) and is also known as 1 astronomical unit (AU). [2]The time it takes for light to travel from the Sun to the respective Planet. Light travels at 186,282 miles/sec (299,792 km/sec). [3]Earth's equatorial diameter is 7,926 miles (12,756 km). [4]Earth's mass is 1.32 x 10^{25} pounds (5.97 x 10^{24} kg). [5]Earth's volume is 2.6 x 10^{11} cubic miles (1.1 x 10^{12} km^3).

The eight Planets as imaged by spacecraft. The top four, known as the Terrestrial Planets, are Mercury, Venus, Earth (our Moon is to the right of Earth) and Mars. The bottom four are the Gas Giants — Jupiter Saturn, Uranus and Neptune. Planet sizes are not to scale.

Minor Planets or Asteroids

Major Asteroids[1]

Name	Longest Length[2]		Average Distance from Sun[3]	Orbital Period	Orbital Inclination[4]
CERES	594 miles	957 km	2.77 AU	4.60 years	10.6∞
PALLAS	325 miles	524 km	2.77 AU	4.62 years	34.8∞
VESTA	318 miles	512 km	2.36 AU	3.63 years	7.1∞
HYGIEA	276 miles	444 km	3.14 AU	5.56 years	3.8∞
INTERAMNIA	204 miles	329 km	3.06 AU	5.36 years	17.3∞
DAVIDA	203 miles	326 km	3.17 AU	5.63 years	15.9∞
EUNOMIA	199 miles	320 km	2.64 AU	4.30 years	11.7∞
EUROPA	188 miles	302 km	3.10 AU	5.46 years	7.5∞
JUNO	170 miles	274 km	2.67 AU	4.36 years	13.0∞
SYLVIA	162 miles	261 km	3.49 AU	6.52 years	10.9∞
EUPHROSYNE	159 miles	256 km	3.15 AU	5.59 years	26.3∞
PSYCHE	149 miles	239 km	2.92 AU	5.00 years	3.1∞
THISBE	144 miles	232 km	2.77 AU	4.60 years	5.2∞
CYBELE	143 miles	230 km	3.43 AU	6.36 years	3.5∞
BAMBERGA	142 miles	228 km	2.68 AU	4.39 years	11.1∞
PATIENTIA	140 miles	225 km	3.06 AU	5.35 years	15.2∞

[1]Presented here are the 16 largest asteroids in the asteroid belt between Mars and Jupiter. It is estimated that there are billions of asteroids having a total mass about 1/1,000 of Earth's mass and a total volume equal to half the diameter of our Moon. [2]Ceres is the only asteroid that is spherical in shape. These lengths may change with new research. [3]For comparison, Mars is 1.5 AU from the Sun and Jupiter is 5.2 AU from the Sun. [4]Inclination to Earth's orbit.

Near-Earth Asteroids. There are three types of asteroids that approach Earth and are categorized as Aten, Apollo and Amor. **Aten** asteroids, which total about 300 asteroids, orbit inside of Earth's orbit. **Apollo** asteroids have orbits that are slightly larger than Earth's, and **Amor** asteroids orbit inside of Mars' orbit. About 3,200 known Amor-Apollo asteroids could potentially cross Earth's orbit.

Facing page. *The asteroid Ida, the second asteroid ever to be imaged. This view of Ida was returned by the Galileo spacecraft in August 1992 on its journey to Jupiter. Ida is about 32 miles in length (52 km) and has a small moon, named Dactyl, revolving around it. Dactyl is about one mile in diameter (1.7 km).*

Page 32. *Orion is one of the most easily and widely recognized constellations. Many of the constellations that we recognize today were also used in ancient times. The Egyptians not only recognized the stars that make up Orion, they used the three belt stars as a pattern for the alignment and size of the three pyramids at Giza.*

THE SOLAR SYSTEM

I. Basic Composition and Structure

A. ***The Sun*** The solar system is composed of eight major planets (4 Terrestrial, 4 Jovian). Pluto is considered by many astronomers to no longer be a planet, since there are now several known objects in orbits similar to Pluto's and of similar size - these are believed to be members of the Kuiper-belt. In addition to the major planets, there are a large number of moons, asteroids, comets, and meteoroids all of which orbit a single star - our Sun. Our Sun is actually a relatively small star (classified as a dwarf) with a moderate surface temperature (approximately 6000K). However, it is so large that its gravitational field dominates all other objects in the solar system. It is also the primary energy souce of the planetary system. Not only does is give light, but it provides much of the the thermal energy to drive the weather patterns on the planets and moons. It is also the source of the solar wind - a high-energy stream of charged particles that fills the solar system. Evidence of this solar wind can be seen in the arora and in the fact that the tails of comets are always directed away from the Sun.

B. ***General Nature of Planetary Motions*** All of the planets of the solar system (and Pluto) orbit the sun in a counter-clockwise direction as viewed from above the ecliptic, the same direction that the sun rotates on its axis. Similarly, many of the larger moons revolve about their respective planets in a counter-clockwise direction, although the outer moons of Jupiter are a notable exception. Likewise, the rotation of almost all the planets is in a counter-clockwise direction. The exceptions to this are Venus and Uranus (long with Pluto). The planet Uranus and Pluto are tilted on their sides, so that their axes of rotation lies almost in the plane of the ecliptic. Venus rotates in a nearly clockwise sense. In addition, all eight of the planets revolve about the sun in nearly the same plane (the ecliptic), which is approximately the plane of the sun's equator. The orbital plane of most planets lies within about 3 degrees of the ecliptic. The greatest exception is Mercury, whose plane make a 7 degrees angle relative to the ecliptic. Pluto has an orbit which has an inclination of 17.1 degrees. The orbits of most of the planets are nearly circular, the planets Mercury and Mars having the most eliptical orbits. (Pluto's orbit is highly eliptical, much more than the planets.)

C. ***Classification of the Planets*** The planets that orbit the Sun fall into two basic groups as illustrated in the schematic below. The number of known moons which orbit each planet is indicated in the parentheses.

$$\overbrace{\text{Mercury(0) Venus(0) Earth(1) Mars(2)}}^{\text{Terrestrial}} \quad \overbrace{\text{Jupiter(63?) Saturn(66?) Uranus(27?) Neptune(13?)}}^{\text{Jovian}} \quad \text{Pluto(3?)}$$

1. ***The Terrestrial planets*** (Mercury, Venus, Earth, Mars) are all made up largely of solid, rocky materials. They are all approximately the same size and density (approximately 4 to 5 times the density of water), with Mars being the least dense of the Terrestrial planets. For this reason, the terrestrial planets are believed to have higher concentrations of the heavier elements than the Jovian planets. A table of relevant data about the Terrestial planets is presented below.

Planet	Density g/cm^3	Bond Albedo	Rot. Per.	Pole Tilt	Rev. Per.	Orbital Inclination	Eccentricity
Mercury	5.43	.12	58.65 d	0	87.97 d	7.005	0.2056
Venus	5.24	.75	– 243 d	177.3	224.7 d	3.395	0.0068
Earth	5.515	.36	1 d	23.45	365.25 d	0.0	0.0167
Mars	3.94	.25	1.026 d	25.19	686.98 d	1.85	0.0934

2. ***The Jovian planets*** (Jupiter, Saturn, Uranus, Neptune) are giant gaseous planets. Their density is much less than the Terrestrial planets (approximately 1 to 2 times that of water) but their mass is much more! Jupiter and Saturn are composed mostly of the gases hydrogen and helium (the two most abundant elements in the Sun) with an unknown interior. (There is some evidence which supports the existence of a liquid or rocky core to these planets.) A table of relevent data for the Jovian planets is given below.

Planet	Density g/cm^3	Bond Albedo	Rot. Per.	Pole Tilt	Rev. Per.	Orbital Inclination	Eccentricity
Jupiter	1.33	.34	9.94 h	3.12	11.86 y	1.305	0.048
Saturn	0.69	.34	10.66 h	26.73	29.46 y	2.487	0.056
Uranus	1.27	.30	– 17.23 h	97.86	84.01 y	0.772	0.046
Neptune	1.64	.29	16.10 h	29.56	164.1 y	1.772	0.010

3. ***Pluto***, since it does not seem to fit into the pattern of the other planets, is no longer considered as a planet, but rather a member of the Kuiper-Belt. It is now considered as little more than a rouge comet or asteroid with three moons.

Planet	Density g/cm^3	Bond Albedo	Rot. Per.	Pole Tilt	Rev. Per.	Orbital Inclination	Eccentricity
Pluto	2	0.3	– 6.387 d	118	248.5 y	17.14	0.248

D. ***Other Vagabonds of the Solar System*** In addition to the planets and their moons, there are also a collection of smaller orbiting bodies in the solar system. These are:

1. The ***Asteroids*** (minor planets) are a collection of smaller, often irregular objects (often described as having the shape of potatoes) in roughly circular orbits around the sun. Most of these lie in the asteroid belt between Mars and Jupiter. The orbits of the asteroids are, however, less confined to the ecliptic, and some orbits actually cross the orbits of the inner planets. A smaller number of asteroids are found about 60 $^\circ$ in front of and behind Jupiter in roughly the same orbit as Jupiter. These asteroids as called Trojan asteroids. The four outer moons of Jupiter that have a retrograde orbit may well be asteroids which have been captured by the gravitationsl attraction of Jupiter. Likewise, the two moons of Mars look very much like asteroids.
2. ***Comets*** are objects which arise at large distances from the sun and orbit the sun in highly elliptical orbits. When they are far from the sun, they are visible only due to reflected sunlight off their solid surfaces. However, as they approach the sun, the exhibit a gaseous tail which is blown away from the sun by the solar wind.
3. ***Meteors*** (falling stars or shooting stars) are visible when friction due to the earth's atmosphere heat them until they glow. These pieces of solar debris appear to come mostly from the orbits of previously observed, or currently observed comets. Strictly speaking, the term *meteor* is reserved for the glowing stone as it passes through the atmosphere, *meteorite* is reserved for such a stone once it strikes the earth, while the term *meteoroid* is the more general term.

II. Orbital Motion of the Planets, Asteroids, and Comets

A. Kepler's Laws of Orbital Motion

1. All bound objects orbit the Sun in eliptical orbits.
2. A line drawn from the Sun to an orbiting object will sweep out equal areas in equal times (i.e., an orbiting object will move faster when it is nearer the Sun and slower when it is farther away).
3. The square of the orbital period is proportional to the cube of the semi-major axis ($T^2 \propto R^3$).

B. Measurements of distances, diameters, masses, rotational periods, etc. in the solar system.

1. Distances are determined by triangulation.
2. Diameters are determined by angular size and distance to planet
3. Mass is determined from Newton's equations of gravity. The period of revolution of a satelite about any object is proportional to the mass of the larger object.

4. Rotational periods of distant objects can be determined by observing how long it takes for the surface features to move around the planet. Likewise it is often possible to perform Doppler measurements.

C. The relative locations and periods of revolution can be determined approximately from Bode's law and Kepler's third law. These numbers are fairly accurate for the planets out to Uranus.

$$\text{Distance from Sun (in AU's)} \approx \frac{[0, 3, 6, 12, 24, 48, 96, 192, 384, 768, \cdots] + 4}{10}$$

Planet	Distance (in AU)		Period (in years)	
	Bode's	Semi-major axis	Bode's	Actual
Mercury	0.4	0.387	0.253	0.241
Venus	0.7	0.723	0.586	0.615
Earth	1.0	1.0	1.0	1.0
Mars	1.6	1.524	2.024	1.881
Asteroids	2.8			
Jupiter	5.2	5.203	11.858	11.86
Saturn	10.0	9.53	31.623	29.46
Uranus	19.6	19.2	86.773	84.01
Neptune	38.8	30.1	241.684	164.1
(Pluto)	77.2	39.8	678.306	248.5

D. Some planets have families of satellites which revolve about them just like a miniature solar system. The larger of these satellites typically revolve around their mother planet in the same direction the planets orbit the sun. Many of the smaller, outer moons of the large gaseous planets, however, orbit in the opposite direction.

IV. Cosmogony: The Theory Of The Evolution Of The Solar System

Any theory which seeks to explain the development of the solar system must consider the following:

A. Orbits of planets are all almost circular
B. Orbits all lie almost in a single plane.
C. The planets revolve in the same direction - the same as the sun's rotation direction.
D. Almost all of the planets and planetary satellites rotate in the same direction.
E. Some planets have families of satellites which revolve about them just like a miniature solar system. These satellites revolve in the equatorial plane of the primary planet (one notable exception is our moon, inclined at about 5 degrees to the ecliptic).
F. There seems to be a simple relationship for the spacing of the planets.

G. These theories must also explain the anomalies - such as the retrograde revolution of some planetary satellites, along with Pluto's unusual orbit.

H. The nebular hypothesis: that the sun and all other objects in our solar system formed at about the same time, condensing out of the swirling gas cloud from which our Sun was born.

V. Characteristics of the Planets and Major Moons as Compared to the Earth

<u>Atmospheres:</u> All planets but Mercury have an atmosphere. The constituents of these atmospheres can be determined using spectroscopy, by looking at the absorption of starlight as it passes through the atmosphere of the planet.

A. Formation and retention of atmospheres
1. The atmospheres of the planets are believed to have come from the outgassing of rocks due to heat. This process occurs on the surface of the earth during volcanic eruptions. The principle gases which are released on the Earth's surface during these eruptions are (in order of relative abundance): water vapor (about 70 to 95 percent), carbon dioxide, sulfur dioxide, traces of nitrogen, hydrogen, carbon monoxide, sulfur and chlorine.
2. The ability of a planet or moon to retain a gaseous atmosphere is determined by the temperature of the planet (how close it is to the sun) and the mass of the planet (thus the graviational attraction of the molecules that make up the gaseous atmosphere).
   a. Lighter molecules may "leave" the planet if they are heated to high enough temperatures, leaving only the heavier molecules behind. This is probably why there is no hydrogen in the Earth's atmosphere. For large planets, the larger gravitational attraction can keep the lighter molecules in the atmosphere.
   b. The atmosphere is more dense at the surface of the planet where it is more strongly attracted to the planet.

B. A Planet's weather is controlled by the Sun
1. The surface of the planet is heated by the sunlight striking the surface (more direct in summer time and less direct in winter) and this causes convection currents in the atmosphere. Low pressures occur where the surface is heated and the less dense air rises. High pressure zones occur where the more dense cold air presses down toward the surface.
2. The coriolis effect, due to the rotation of the planet, causes wind currents to move in circular patterns. On the Earth's surface, a counter-clockwise rotation occurs in the Northern hemisphere about a low-pressure zone; a clockwise rotation about a high-pressure zone.
3. On the Earth, water is evaporated at the surface by the heating of the sun. This evaporated water rises into the atmosphere where it cools and condenses upon nucleation sites (dust, salt crystals, etc.) forming clouds. The winds

move the clouds across the surface of the earth which effectively shields some sections of the surface from the sunlight. The albedo of a planet is largely influenced by the cloud cover. Venus, which is completely covered by clouds at all times has an albedo of about 60%.

4. On other planets, other substances are evaporating and condensing in the planet's atmosphere. On Mars, for example, the temperature is cold enough to freeze out Carbon Dioxide forming dry ice caps on the North and South poles.
5. The Earth's atmosphere and the oceans moderate the temperature differences on the Earth's surface. On Mars, however, there may occur much larger temperature differences and large wind storms may be generated which pick up dust into the atmosphere causing visibility to fall to zero. These dust storms may last months.

C. The Beneficial aspects of our atmosphere
1. Our atmosphere supplies the necessary gases from life.
2. The atmosphere supports the weather which provides life-giving water for plant and animal life.
3. The atmosphere protects the surface from ultraviolet light which can destroy living cells.
4. The atmosphere helps to moderate the temperature of the planet.
5. The atmosphere burns up incoming meteoroids.

D. Composition of the atmospheres of the Terrestrial Planets (Mercury has no atmosphere)

	Venus	Earth	Mars
Nitrogen	4%	77%	3%
Oxygen	Almost zero	21%	Almost zero
Carbon Dioxide	96%	Almost zero	95%
Other gases	Almost zero	2%	2%

E. Structure of the Earth's atmosphere [see transparency]

a. The Troposphere (8 km at poles; 16 km at equator) is the region where the temperature decreases with height and where all weather occurs.

b. The Stratosphere is a region which extends to 80 km with an almost constant temperature of -50°

c. At the top of the Stratosphere is the Mesosphere, a warm region containing ozone which absorbs the ultraviolet rays from the sun and heats the atmosphere.

d. The temperature of the atmosphere then cools again with altitude until it reaches a height of about 80 km where the temperature begins to rise as the atmosphere thins into the region of space. This is the Thermosphere (80 km-400 km) temperature rises. At 400-500 km the temperature has risen to about 1000°C.

e. Exosphere (above 400 km) mostly O and N and ions. (The region above 50 km is usually known as the ionosphere.)

F. Compare the thermal structure of the atomospheres of Venus and Mars. Notice that there is no region where the temperature rises appriciably with altitude until the atmosphere begins to unite with interplanetary space.

Planet Interiors: The interior of the Earth has been studied primarily based upon seismic studies of earthquakes. This is also true of the Moon. No other planet has been studied seismically. All ideas of the interiors of other planets are theoretical based upon other evidence.

A. The Earth's Interior
    1. The Earth's Density. The density of the outer layer of the Earth is 2.7 g/cm^3, whereas the total average density is 5.5 g/cm^3. This implies that the density of the material near the center of the Earth must be very dense.
    2. Structure of the Earth's interior
        a. The Crust is the thin outer layer of the Earth's surface. This layer is “brittle” and will break and crack easily. The crust is relatively thin under the oceans (as thin as 5 km) but is relatively thick underneath the continents.
        b. The crust rests on top of a semi-solid mantle. Although the temperature in the mantle is high enough to melt rock, this rock is under extreme pressure and remains semi-solid. When the pressure is released, as in the case of an earthquake, this rock suddenly melts and the less dense molten material (magma) moves toward the surface of the earth. If there is a crack in the rock the magma may flow out onto the surface of the Earth. Magam which flows onto the surface is called lava.
        c. From seismelogical studies, we know that a liquid core lies at the center of the earth. There is evidence that the core is acutally composed of an outer liquid region and a rocky inner region. This core is believed to be compose of iron and nickel.
    3. The temperature of the interior increases about 1°C with every 30 m of depth. This temperature gradient appears to arise from two sources:
        a. conduction from the hot inner core
        b. radioactive processes within the mantle are believed to produce 80% of the thermal rise.

B. Plate Tectonics
    1. Evidence supports hypothesis of moving continents.
        a. New crust is "created" at mid-ocean ridges.
        b. Old ocean crust is subducted (carried under) other layers of crust (particularly continental crust). This occurs at plate boundaries which are very active geologically (volcanoes and earthquakes).
    2. The Hawaiian islands an example of volcanism occuring over a hot mantle plum. This can be compared with the large volcanic mountains which form on the planet Mars, where we believe the plates are locked, implying that plate tectonics is no longer active.
    3. Plate tectonics would literally reshape the outer crust of the Earth over a period of time, obliterating the evidence of past meteor impacts.

4. Volcanic activity can uplift a region and cause the upper crust to crack. When the magma receeds, the raised surfaces sometimes collapse creating compression regions.

Magnetic fields

A. The Earth's magnetic field is a relatively weak field, approximately 0.3 Gauss at the surface.
B. The shape of the Earth's magnetic field can be demonstrated with a permanent magnet. The fields posses two opposite poles. The Earth's poles do not correspond exactly to the poles of the rotational axis. The north magnetic pole is actually in Northern Canada and appear to change slowly in time. There is evidence that the poles have actually moved quite a lot in the past, and that the poles have actually change polarity a number of times over the lifetime of the Earth.
C. The effect of magnetic fields on charged particles.
    1. Charged particles from the Sun strikes the Earth's Magnetosphere and are directed toward the magnetic poles. The charged particles collide with the molecules in the upper atmosphere and produce what we call the Aurora (the Northern and Southern Lights).
    2. There are regions of trapped charged particles within the magnetosphere, called the Van Allen Belts.
D. The Magnetic Field of the Planets, and the Production of Magnetic Fields.
    1. The following chart gives the magnetic fields at the surface of the planets (or at the cloud-tops).

Planet	**Field Strength** (Gauss)
Mercury	0.002
Venus	$\approx$ 0.0
Earth	0.31
Mars	$\approx$ 0.0
Jupiter	4.25
Saturn	0.21
Uranus	0.23
Neptune	0.14
(Pluto)	Unknown

    1. It is believed that the magnetic field of a planet is a result of a rotating, metalic, liquid core.
    2. Typically planets and moons which rotate very slowly do not have an appreciable magnetic field. This is true of the Moon and of Venus. And although Mars rotates at the same rate as the Earth, it posseses no appreciable magnetic field. This may be because the core is no longer liquid.
    3. The larger gas planets have magnetic fields comparable to, or larger than Earth's. This is probably because of their rapid rate of rotation, and is an

indication that they possess a liquid core. Jupiter, a rapidly rotating planet, has a very large magnetic field, nearly 15 times larger than that of Earth's. However, the field of Saturn is roughly the same magnitude of Earth's. This may be an indication of the relative sizes of the liquid cores of Jupiter and Saturn.

4. An interesting puzzle is why Mercury possesses any magnetic field whatsoever, since it's rotation rate is so low.

The moon: our nearest, best explored neighbor in the solar system.

General properties

I. There is no atmosphere and no water on the lunar surface (although there is some evidence that there may be ice in some of the craters near the poles)
   A. The lack of an atmosphere means that there is no weathering to change the surface of the moon.
   B. *None of the lunar rocks contains any trace of water bound inside its minerals*.

II. Temperature
   A. The temperature on the surface of the Moon varies from about 100°C at noon (hot enough to boil water) to a chilly -100°C at midnight (cold enough to liquify and freeze some gases).
   B. During and eclipse, the change in temperature may be as large as 150°C in one hour. This is much more than would be expected if the surface was rock like on earth. However, a fine powder would absorb heat but not conduct it very well! And this is just what the surface of the Moon is made of: fine powder derived from centuries of meteorite empacts on the surface.
   C. The large variation in temperature on the Moon is quite unlike that of Earth, which is covered by 70% water and an atmosphere which moderate that temperature. Variations in temperature on the surface of the earth are of the order only of 10 - 20 $^{\circ}$C.

III. Magnetic Field
   A. As mentioned above the Moon has no appreciable magnetic field. This is probably because of the extremely slow rotational rate, and perhaps because the moon may no longer have a liquid core.
   B. However, there are weak local fields.

IV. The Moon's interior
   A. The mass and mean density of the moon is less than that of Earth's. In fact the mean density of the Moon is roughly equal to the density of the rocks on the surface of the Moon. This means that the Moon probably does not have a denser inner core.
   B. Surface irregularities in the moon's mass distribution have been discovered. The mass is concentrated in the areas of the Marea. These are called Mascons (mass concentrations). They may be:
      1. Submerged meteorites of large mass.
      2. Regions of subsurface magma or lava rock, or

   3. Just a concentration of more massive lava rock at the surface in the Mare.
  - C. The center of mass of the moon is slightly shifted toward the earth. Perhaps this is what has "locked in" the Moon's rotation and revolution rates, causeing the same side always to face Earth.
  - D. The moon's crust appears to be much thicker than earth's, and perhaps more uneven (60 km deep on the Earth side, 150 km on other side).
  - E. The Moon is far less active seismically than the earth. There is no evidence of tectonic activity. The natural seismic activity of the Moon appears to be correlated with times when the earth exerts its greatest tidal stress on the lunar crust.
  - F. The surface material transmits seismic waves slowly. This would imply that the surface is not very rigid - perhaps loose rocks, like rubble. At greater depth the speed increases until at 1000 km the waves do not appear to be transmitted efficiently which may indicate a hot or molten core.
  - G. In 1972, a meteor struck the moon while our seismometers were still activated. The S-waves from the shock failed to penetrate the core of the moon, indicating that the core is still liquid, or nearly so.

- V. The Moon's Surface Features
  - A. The Maria (seas) are large smooth plains which appear darker than the surrounding area
    1. Most are roughly circular in shape.
    2. These are actually speckled with 1000's of tiny craters.
    3. The floors are covered with basaltic material which is very porous (having a density of 0.7 - 1.2 g/cm^3).
    4. The large maria occur only on the near side of the moon!
  - B. Craters
    1. Craters may be as large as 200 km in diameter
    2. Most craters are found in the highland regions, but a few are found in the maria. This seems to indicate that the Maria are more recent geologic features.
    3. Most are circular and have outside walls
    4. Larger craters have a mountain peak in the center
    5. Some groups of craters follow ridges or faults and thus may be volcanic.
  - C. The region other than the Maria is known as the Highlands. Many of the mountains on the Moon are very large. The highest mountains are about as high as the Himalayas on earth.
  - D. Other surface features
    1. Alpine Valley
    2. crevasses or rills
    3. Rays which radiate from craters

- VI. Composition of the surface
  - A. Oxygen is the most abundant element in the surface and is found in the form of silicates.
  - B. Silicon is the next most abundant element

C. The Mare basalts are similar to volcanic basalt material on earth, but with less iron and volatiles.
D. The most common minerals are plagioclase and pyroxene.
E. The oldest rocks, found in the highlands are about 4.4 billion years old, while the rock in the maria are about 3.1 billion years old. By comparison, almost all the rocks on Earth are younger than 3 billion years old (although there are a few which date to about 4 billion years). But remember that the earth's surface has been "recycled" by plate tectonics and erosion.

<u>The Moon's Origin and the Origin of It's Craters</u>

I. Three main theories of the Origin of the Moon
   A. The Moon separated by fission from the earth when they first formed.
   B. The Moon formed elsewhere and was later captured.
   C. The Moon accreted from material revolving about the earth.
   D. The Moon formed when a large asteroid collided with the Earth and knocked out a large chunk of the Earth's outer, less dense material. The fireball that resulted would have caused the volatile water vapor to be released into space.
II. Origin of the Craters
   A. The accreted materials colliding to form the moon formed craters (this also happened to the earth, but erosion erased the record)
   B. Some are probably volcanic in origin

Discussion of Individual Planets

<u>Mercury</u>

I. Orbit about the sun
   A. Except for Pluto, Mercury's orbit around the Sun is the most elliptical: the maximum and minimum distance from the Sun is as much as 40% of average distance, compared to less than 4% for the Earth.
   B. Distance from Sun: 0.4 A.U. (1 A.U. is mean distance from Earth to Sun)
   C. Maximum elongation angle from the Sun is 28° which means that it is within 2 hours of the sun's position (two hours before sunrise or two hours after sunset).
   D. Since Mercury can only be observed near the horizon when it is dark enough to be observed, the light must pass through a long path of atmosphere--which causes very poor "seeing"-- as a result, observations from the earth have been very limited.
II. Rotation
   A. Based upon early Earth-based telescope observations it was once believed that the rotation period of Mercury was equal to the revolution period of 88 days.
   B. More recent radar measurements have shown (using Doppler shift) that the siderial rotation period of Mercury is 58 days, 16 hours.

   C. The combined rotation and revolution of Mercury yields a 176 earth-day-long solar day.

III. Other ground-based observations
   A. Albedo (fraction of sunlight reflected from surface)
      1. an ideal mirror 100%
      2. best real mirror 96%
      3. a black cloth 0%
   B. Mercury's geometric albedo is only about 10% (comparable to the moon)

IV. Observations from Mariner 10 (first flyby March 29th to April 3, 1974).
   A. Photographic Results - objects observed
      1. craters much like moon - Mercury resembles the far side of the moon
      2. maria
      3. scarps
         Explanations: Impact, vulcanism, shrinkage of crust as core solidified
   B. Results from infrared observations
      1. Fine dust on surface
      2. Temperature varies from 700K (hot enough to melt lead, zinc) to 100K (cold enough to freeze CO_2).
   C. Other observations: A big surprise came when it was discovered that Mercury had a magnetic field (although it is only about 1% of earth's).

<u>Venus (the evening star)</u>

I. Orbital motion
   A. Orbit about sun - period of revolution is 224.7 days in a nearly circular orbit
   B. Rotational period is 243 days, nearly as long as the period of revolution, *but is in the opposite direction from the other planets*!

II. Observations from earth
   A. Optical:
      1. Venus is often called Earth's sister planet because of similarity in mass, size, and density and the fact that Venus is covered with clouds.
      2. The surface is always covered with dense clouds, so that the surface was completely unknown until the use of radar.
      3. Venus is never observed farther from the sun then 48°
      4. Venus is the brightest object in the sky other than the sun and moon.
   B. Radar studies
      1. The temperature on Venus is very hot, reaching as high as 750 K. This is due to the greenhouse effect.
      2. With the use of Earth-based radar a crude map of the surface of Venus was possible. This was later improved by sending spacecraft to orbit Venus. The Magellan space craft mapped the entire surface using radar.
   C. The atmosphere is heavy atmospheric pressure being some 90 times that of Earth's. The clouds of Venus are composed primarily of H_2SO_4 (sulfuric acid).

<u>Mars</u>

I. Size of Mars

The diameter of Mars is approximately 1/2 that of Earth. It therefore has about 1/8 the volume (or mass), so that the gravitational attraction on Mars' surface is roughly 1/2 that of Earth.

II. Orbital Motion

A. Revolution - the revolution period is approximately 687 earth days, or about 2 earth years. The orbit, however, is much more eccentric than Earth's, being nearer to the sun during the northern winter season, and further from the sun during the northern summer season.

B. Rotation - rotational period is 24 hr, 37 min, 22.6 sec, nealy equal to that of Earth's.

C. The orbital axis is tilted at about 25°, nearly equal to that of earth. This gives rise to seasonal variations much like the Earth's, but with bigger differences in the northern and southern seasons because of the eccentricity of the orbit.

D. Surface temperatures measured at the Viking Landers lange from as low as 150K (about -125°C or -190°F) to highs of over 300K (27°C or 80.6°F). Daily temperature variations of about 35 to 50 °C very measured.

III. Atmosphere

A. Composition - 95% CO_2, 2% N_2, little O_2.

B. Pressure only about 1% that of Earth

C. Because there is little atmosphere and no surface ocean to moderate the temperature differences, there are large pressure differentials which cause high winds. These winds may generate dust storms which may cover large portions of the planet for weeks or months at a time. The larger storms typically occur during the summer season in the southern hemisphere when Mars is closest to the sun.

IV. Surface Features

A. Mars appears to have two distinct regions.

1. In the southern hemisphere, Mars appears to be covered with craters, much like our Moon.

2. The Northern hemisphere, however, is relatively smooth with a large uplifted region known as the Tharsis Bulge.

a. Located on the Tharsis Bulge are numerous volcanoes, the largest of which is Olympus Mons which measures 600 km at the base, 25 km high with a caldera 65 km wide. By comparison, one of the largest shield volcanoes on the Earth is Mauna Kea in Hawaii which rises only 9 km above the ocean floor. The fact that Olympus Mons is so much larger than Mauna Kea suggests that the motion of the crustal plates on Mars had ceased before the eruptions that created Olympus Mons. In addition, there are no features similar to mid-ocean ridges observed on Mars.

b. Associated with the Tharsis Bulge is a systems of canyons called the Valles Marinaris. This is apparently a rift valley approximately 5000 km (3000 mi) long (or the distance from San Franscisco to New York) and 5 miles deep. [Note: This rift valley would swallow the Grand Canyon which is only 1 mile deep and the order of 100 miles long.] It is interesting to note that Earth, Venus, and Mars all have large rift zones.

B. Other Surface features
   1. Sand dune regions are located near the north polar cap. These are probably due to the prevailing winds that blow the Martian dust across the planet surface.
   2. There are features which appear much like dry river beds with tributaries. The only apparent explanation is that there may have been water on the surface at some time in the past.
   3. What has happened to this water?
      a. Liquid water cannot exist under the present atmospheric conditions on the surface of Mars. The atmospheric pressure is too low.
      b. Some water, however, may be trapped in the form of ice.
         (1) Some water appears to be trapped in the northern polar ice cap. During northern summer, this ice cap is greatly reduced in size and only a small ice cap remains - perhaps a water ice cap remaining after the sublimation of the carbon dioxide.
         (2) Other water may be trapped below the surface in the form of ice. Some craters appear to have flow zones around the outsides which may indicate melting of subsurface ice to produce mud-like flow features.
      c. Some of the water has evidently combined with surface rocks to form limonite (2 Fe2O . 3 H2O) a reddish iron compound, which may be the source of the reddish color of the surface.

V. Moons of Mars
   A. Mars has two moons
      1. Phobos (Fear), 27 km across, is the inner moon orbiting every 7 hr 39 min This is *faster* than the rotational speed of Mars, so that it appears to move from west to east through the Martian sky.
      2. Deimos (Panic), 15 km across, is the outer moon, orbiting every 30 hours. This period is only slightly slower than the rotational period of Mars, so that Deimos takes about 3 days to cross the Martian sky (it is almost in a synchronous orbit).
   B. The rotational motion of these moons is "locked" to the planet so that their rotational periods and periods of revolution are the same.
   C. Both moons are cratered chunks of rock, not spherical like the Earth's moon and appear to be very similar to some of the asteroids. Some have suggested that these are indeed captured asteroids from the asteroid belt.

Jupiter

I. Jupiter is the largest planet in the solar system, containing 2/3 of all the planetary matter of the solar system (i.e., excluding the sun). As a Jovian planet it is composed mostly of gases, but probably has a liquid core. The mass of these gases and the associated gravitational energy causes Jupiter to continue to radiate energy at a rate of about 2 times that of the sunlight incident upon the surface! [2010 scenario]

II. Orbital Motion
   A. Revolution about the sun - $\approx$ once every 12 earth years with a slightly eccentric orbit
   B. Rotational period is $\approx$ 10 hours (surface features move very fast). The tilt of the rotation axis is only about 3° which means that seasonal variations are slight due to the eccentricity of the orbit.
   C. The planet has a slightly oblate shape due to the rapid spinning on its axis.

III. Atmosphere
   A. Composition - $\approx$ 86% hydrogen and 14% Helium, which is nearly the same proportions as the sun. A small amount of methane, ammonia and water vapor are also present.
   B. The albedo is approximately 51%
   C. The gases making upon the atmosphere appear to have complex cloud-like features. Dark, brown belts are observed mixed with lighter colored zones.
      1. The temperature of the atmosphere increases with depth into the atmosphere and probably produces layers of clouds with differing compositions. The zones appear to be layers of rising, warmer gases, while the belts appear to be falling, colder gases.
      2. These complex patterns of turbulent winds appear to move faster near the equator and slower near the poles. Wind speeds of up to 500 km/hr may be observed.
      3. Some persistent "storms" are observed to pass across the outer layers of the atmosphere. The most noticable one being the great red spot which has been observed for at least the last 300 years.
         a. This spot is really a cyclonic storm with a diameter approximately equal to 3 earth diameters.
         b. This spot has exhibited slight changes in size and shape over this period, but has never disappeared. Smaller storms have been observed to come and go.
      4. Large lightning storms are observed in the upper atmosphere of Jupiter
   D. Sharp bursts of radio waves are associated with Jupiter and appear to arised from an interaction of charged particles with a large magnetic field ($\approx 10 \times$ the Earth's field). This is an indication that the center of Jupiter may be a rapidly rotating liquid. Associated with this large magnetic field are large-scale auroras near the poles of Jupiter. Jupiter's magnetic poles are *opposite* to that of Earth, but Jupiter rotates in the same dirction as Earth.

IV. Moons and Rings
   A. Interior to the moons, Jupiter has a thin ring, first observed by the Voyager spacecraft.
   B. Jupiter has at least 58 moons, with four of the inner moons (the Gallilean moons) visible in a moderately-sized telescope. One of these, Ganymede, is the largest moon in the solar system.
   C. The moons may be classified according to position and size into three groups:

1. The innermost 4 moons are small
2. The next 4 moons are the large Gallilean moons (discoverd by Gallileo in 1610)
   a. Io - the only object other than earth which exhibits active volcanos.
      (1) As many as 8 simultaneously erupting volcanos have been observed, and these eruptions last for long periods of time.
      (2) The volcanos probably result from the tidal forces between Jupiter, Io, and the other Gallilean moons.
      (3) The surface of Io appears to rise and fall by as much as 100 meters.
      (4) These volcanos appear to be largely sulfurous.
   b. Europa appears to be covered with "cracked ice" - there are no appearant craters.
   c. Ganymede is the largest moon in the solar system, larger than Mercury. It exhibits many craters and its grooved terrain shows faulting.
   d. Callisto
3. The outer moons orbit far from Jupiter and are typically very small in size. Many of these outer moons revolve in a *retrograde* fashion (in a direction opposite that of Jupiter's revolution and rotation, and the revolution of the other planets).

Saturn

I. Saturn is the most distant of the naked-eye-visible planets. The most distinctive feature of Saturn is its system of rings, visible in a moderate-sized telescope. Saturn is the least dense planet, with a density less than water.
II. Orbital Motion
   A. Its revolution period of approximately 30 earth years
   B. The rotational period is, like Jupiter's, approximately 10 hours, but the axis of rotation is tilted about 27° with respect to the sun.
III. Atmosphere
   The atmospheric composition of Saturn is essentially like that of Jupiter, although Saturn does not exhibit the contrast in cloud colors, and visible long-lasting storms (although storms have been observed).
IV. Rings and Moons
   A. Rings
      1. The rings of Saturn are located along the plane of the equator, so that they are tilted at about 27° with respect to the ecliptic. This means that we see the rings with different orientations at different times. Sometimes they appear edge-on, and are almost invisible since they are very thin.
      2. The rings are actually composed of small bits and pieces of ice and rock (the larger pieces being approximately house sized.
      3. The ring is located inside the Roche limit - the distance from the planet where the tidal forces are greater than the force which would allow a moon to gravitationally coalesce.

4. This ring system is roughly the diameter of the Earth-Moon distance.
5. The Cassini division appears to be a gap in the ring system, but is actually filled with small sized particles.

B. Moons

1. Saturn has at least 30 moons, most being small and irregular
2. Saturn's largest moon, Titan, was discovered in 1655 by Christian Huygens, and is the only moon in the solar system to have an appreciable atmosphere. The next four of the larger moons of Saturn (Tethys, Dione, Rhea, and Iapetus) were discovered between 1671 and 1684 by Cassini.
3. There are a number of "shepherd" moons which orbit the planet in the ring system.

Uranus

I. Orbital Motion

A. Uranus was discovered in 1781 by William Herschel and was the first planet discovered which had not be known to the ancients. It had been plotted on several star charts as a star. Because it is so distant from the Sun (about 19 A.U.) it requires 84 years to complete an orbit of the sun.

B. The rotational period of Uranus is 17 hours - 14 minutes (based upon measurements of a periodic radio burst arising from the planets magnetic field), but the axis of rotation is parallel to the ecliptic, meaning the pole of the planet sometimes points directly toward the sun, sometimes directly away. Thus some regions of the planet are in the dark for about 42 earth years. Based upon infrared radiation, the surface temperatures have been measured at a cold 58K ($-215°$C or $-355°$F), but strangely enough, both poles and the equator appear to be at about this same temperature. [There does not appear to be an internal heat source as is found on Jupiter, Saturn and Neptune.]

II. Uranus' Rings

A. Uranus' ring system was first discovered when light from a star was occultated by Uranus. Remember that this is a technique used to determine the atmospheric composition of a planet. About half and hour before the predicted occultation, a series of dips in the light intensity occured which were later echoed after Uranus occulted the star. These "rings" were later observed when the Voyager spacecraft passed by Uranus.

B. There are now 9 known rings.

III. Uranus' Interior and Magnetic Field

A. Uranus' magnetic field was found to be about 50 times stronger than Earth's. However, the strangest thing is the orientation of that field

B. The magnetic field makes an angle of about 60° to the axis of rotation and the center of the field is offset from the center of the planet by about 1/3 of the planet's radius! This strange orientation may have resulted from a violent impact in the past.

IV. Uranus' Moons

A. Uranus' moon Miranda demonstrates an enourmous amount of "disfigurment". There are cliffs which rise 12 km above the surface which has diameter of only about 240 km! It is believed that this moon may have collided with

Uranus to cause the tilt of the axis and the offset of the magnetic field of the planet.

B. Uranus has at least 17 moons (4 more are awaiting confirmation).

<u>Neptune</u>

I. Orbital Motion
   A. Neptune is about 30 A.U. from the Sun and requires about 164 Earth years to complete an orbit. Its rotational period is 1611 hours.
   B. Neptune was discovered as a result of Uranus' slight deviation in its orbit as predicted by Newton's laws. Galileo, however, may have actually been the first to see Neptune. He recorded that position of stars when he observed the moons of Jupiter, and noted that one of these stars appeared to have moved. By looking at Neptune's orbit, we have determined that Neptune was indeed lined up with Jupiter at the time of Galileo's observations.

II. Atmosphere
   A. The atmosphere of Neptune, like Uranus, contains a large amount of methane which causes the planet to appear a greenish blue.
   B. When observed by the Voyager space craft, Neptune had a large storm-like structure, similar to the great red spot on Jupiter. This was found to be a large anti-cyclone. However, when observations of Neptune were made later with the Hubble Space Telescope, this storm had disappeared.

III. Interior and Magnetic Field
   A. Infrared measurements establish a temperature of 59K for the surface of Neptune, but this is warmer than expected based solely on solar heating. It was found that Neptune, like Jupiter and Saturn, radiates about 2.7 times the amount of energy incident upon it in the form of sunlight.
   B. The magnetic field of Neptune is also tilted at a large angle with respect to the orbital axis, and displaced from the planet's center. Thus, the arguement that Uranus suffered a collisions which modified its field may be questionable, unless Neptune, too, underwent such an event. Two such similar events seem questionable. Maybe there is another explanation!

IV. Moons
   A. Neptune has at least 8 moons (+4 newly discovered ones are awaiting confirmation).
   B. Neptune's moon Tritan has a thin atmosphere of Nitrogen and its surface is apparently formed from methane ice and water ice. The presence of "ice volcanoes" were observed by Voyager.

<u>(Pluto)</u>

Althougth no longer considered a planet, the following information is interesting in comparing Pluto with the major planets of our solar system.

I. Orbital Motion
   A. Pluto, for many years considered the outermost known planet, is a deviant. It has the most eccentric orbit (sometimes coming closer to the Sun than

Neptune), and its orbit is inclined to the ecliptic by more than 17° (Mercury is inclined by about 7°, and all other planets lie within 3° of the ecliptic).

B. Pluto's orbital period is about 248 Earth years.

II. Surface Features

A. Little is known about Pluto because it is so far away. Variations in brightness are observed around the planet. The equatorial region seems darkened.

B. The surface temperature is very cold - less than 60K.

III. Pluto's Moons

Pluto has three known moons, Hydra (134340 III) and Nix (134340 II), as well as its companion moon, Charon (134340 I). At about 1,186 km (737 miles), Charon's diameter is a little more than half of Pluto's, and is only 8 Pluto diameters from Pluto (forming a "double-planet" system). [Pluto is only about 0.2 times the size of Earth.] Gravity has locked Pluto and Charon into a mutually synchronous orbit, which keeps each one facing the other with the same side. Many moons - including our own - keep the same hemisphere facing their planet. But this is the only case in which the planet always presents the same hemisphere to its moon. Charon was discovered in 1978, while the two additional moons, Hydra and Nix, were discovered in 2005.

NASA launched its New Horizons spacecraft to Pluto and Charon in January 2006, and it should arrive in 2015, becoming the first spacecraft to visit them. In preparation, the New Horizons project is organizing a search for additional moons of Pluto, using ground-based telescopes and possibly the Hubble Space Telescope.

IV. Atmosphere

Based upon occultation studies, Pluto has a slight atmosphere.
When occulted light dims quickly, the edge of the planet abruptly cutting off the stars light, we conclude that there is little or no atmosphere. However, when the light dims gradually, we conclude that there is an atmosphere present. Variations in the dimming pattern indicate a differentiated atmosphere.

V. Internal structure

All we really know about Pluto is that its density is about 2 g/cc, a little more than an "icy" world, but not much.

Kuiper-Belt Objects

I. Since the discovery of Pluto a few dozen other objects have been discovered with orbits beyond Neptune. Gerard Kuiper had suggested their existence before they were discovered as the location of objects which sometimes become "comets", much like Halley's comet. The aphelion of Halley's comet is about the same distance from the Sun as Pluto's orbit, although Halley's orbit has a very different orientation than Pluto's orbit.