Descriptive Chapters

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Chapter 1

Descriptive Chapters

1.1 Description

This database contains a series of descriptional chapters, linked into by other documents. As a result, no table of contents exists for the file.

1.2 The Sun - Fast Facts

```
Mass...............................1.9891e30 kg  (332948 times that of Earth)
Equatorial radius.....................696000 km  (109.12 times that of Earth)
Surface gravity.........................274 m/s^2 (27.9 times that of Earth)
Apparent semidiameter at 1 AU.........959.64 arcseconds
Average density.......................1.41 g/cm^3
Inclination of equator to ecliptic......7.25 degrees
Magnitude, apparent...................-26.8
Magnitude, absolute....................4.77
Average surface temperature............5500 degrees C
Spectral classification................G2-V
Age..........................4,600,000,000 years
Expected life remaining........5,000,000,000 years
Revolution period in Milky Way...200,000,000 years

Rotational periods (*):
  Equatorial............................25.4 days
  Polar...................................36 days
  Internal................................27 days
  Adopted for heliographic longitudes..25.38 days

Motion relative to nearby stars:
  Direction (right ascension)............18 hours
  Direction (declination)................30 degrees
  Velocity...........................19400 m/s

Distance from Earth:
  Shortest.....................147,098,447 km (0.9832923836 AU)
  Average......................149,598,023 km (1.0000010178 AU)
  Greatest.....................152,097,599 km (1.0167096520 AU)
```

```
 Composition (by number of atoms):
     Hydrogen...........................92.1%
     Helium..............................7.8%
     Oxygen..............................0.061%
     Carbon..............................0.030%
     Nitrogen............................0.0084%
     Neon................................0.0076%
     Iron................................0.0037%
     Silicon.............................0.0031%
     Magnesium...........................0.0024%
     Sulfur..............................0.0015%
     Others..............................0.0015%
* Since the Sun is basically a huge ball of gas, it does not rotate as a solid
body.  As can be seen from the rotational periods, gas near the equator takes
less time to rotate around the Sun than gas at the poles.  This
differential rotation can also be observed with the gas giant planets Jupiter,
Saturn, Uranus, and Neptune.
```

1.3 The Sun - Structure and Nuclear Processes

```
Like most bodies in the solar system, the Sun is comprised of several layers,
each of which is different from the others in some fundamental respects.


 The Core
 ========
 Occupying the inner third of the Sun, the core reaches a temperature of
15,000,000 degrees C (27,000,000 degrees F), and a pressure 250,000,000,000
times more intense than that of the Earth's atmosphere at sea level. Since
nuclear fusion requires such extreme conditions, the core is the only place in
the Sun where it can occur.

Through the process of nuclear fusion, four hydrogen nuclei (four protons)
collide together and form an alpha particle, or helium nucleus (consisting of
two protons and two neutrons).  However, the alpha particle is about 0.7%
lighter than the four protons.  The missing mass is converted to energy in the
form of photons, as specified by Albert Einstein's famous equation: E=mc^2.
These photons then begin their long journey towards the surface of the Sun, and
eventually out into space.

In one second, the Sun converts 5 million metric tons of hydrogen into energy.
This output of a single second would be sufficient to satisfy the world's
current energy requirements for 1 million years.


 The Radiative Zone
 ==================
 The Radiative Zone occupies the region of the Sun encircling the core,
reaching out to within 150,000 km of the surface.  When energetic photons from
within the core strike atomic nuclei in this layer, the photon is absorbed, and
another, slightly less energetic photon reemitted.  In this way, the decreasing
photon energy causes the radiation to shift from gamma rays (as produced in the
core), to X-Rays, to extreme ultraviolet, to ultraviolet, to visible light.
Though an unimpeded photon, travelling at the speed of light, would only take
```

slightly over 2 seconds to emerge from the Sun, these frequent collisions in random directions result in it taking 50 million years, on average, for energy generated within the core to reach the surface.

As we move out from the center of the Sun through the radiative zone, we would find the temperature, pressure, and density (as well as photon energy) continually decreasing. Eventually, the temperature would be around 2,500,000 degrees C (4,500,000 degrees F) with a density about equal to that of water.

The Convection Zone

Within the Core and Radiative Zone, the temperature is so high that atoms are stripped of their electrons; they basically consist solely of their nuclei. By the time that the Convection zone is reached, the temperature has cooled to the point that the free electrons are starting to recombine with these nuclei, becoming more opaque to radiation. This acts as a blanket and results in a large temperature gradient going towards the surface.

Now, the energy is carried towards the surface by another process in addition to radiation - convection. Heated fluids, because of their lower density, rise while cooled fluids fall. A fluid heated from below will rise in a column until it cools. At that point, it will move aside and fall to be re-heated, continuing the process. Fluid trapped in this cycle is said to be part of a "convection cell".

Convection can occur at any scale. Convection currents may be observed in a warm pot of water (though if boiling, the convection becomes turbulent and more difficult to observe). Towering thunderheads usually evolve their characteristic appearance as warm, moist air rises through the center of the cloud. As the air cools, the moisture condenses to form the cloud, while the air moves aside and falls back down.

Convection cells on the Sun are much larger, however. The top of a column can be 1000 km or more across. These convection cells may be observed in high resolution white light images of the Sun. Since convection patterns appear as 'granules', the effect is often referred to as 'granulation'.

View picture of granulation

The Photosphere

When we look at the Sun, we see the region known as the Photosphere. It is a thin layer, perhaps only 100 km in depth, that produces the radiation transmitted into space, since at its distance from the center of the Sun photons are more likely to escape than be re-absorbed. The Photosphere is considered to be the innermost layer of the Sun's atmosphere.

The conditions in the photosphere are much less severe than elsewhere in the Sun. The temperature has dropped to a relatively cool 5500 degrees C, the pressure is only one hundredth that of the Earth's atmosphere at sea level, and the density is about one hundred millionth that of water.

The sun's limb (edge) appears darker than at its center, due to an effect known as limb darkening. Click here to see an example picture.

Since light travelling through the Photosphere is partially absorbed by material located there, our line of sight can only see so far. When we look at the center of the Sun's disk, we are looking through less of the Photosphere than when we observe near the limb. As a result, we see deeper into the Photosphere near the centre. The limb appears darker because our line of sight ends higher in the atmosphere, where the temperature is cooler.

The Photosphere and other atmospheric layers are the home to a wide variety of features which are visible on the Sun from the Earth. See Solar Activity for more information.

The Chromosphere

This is a level of the solar atmosphere immediately above the Photosphere, extending about 2500 km out. At approximately 500 km above the Photosphere, the temperature is only 3000-3500 degrees C. However for some reason not yet fully understood, the temperature then rapidly increases to 1,000,000 degrees C at its outer reaches. It is felt that the heating is due partially to a dramatic density decrease (the density can be as low as 100 trillion times less dense than water), as well as mechanical energy added to the Chromosphere from the Convection Zone. Granulation can overshoot hundreds of kilometers into the Chromosphere. Due to the decreased density, higher particle velocities are possible, resulting in a higher temperature.

Also present in the Chromosphere are gas streams shooting up from the Photosphere, known as spicules. These can be 800 kilometers thick, up to 15,000 kilometers high, and last for as long as 15 minutes.

The Corona

The outermost atmosphere of the Sun is known as the "Corona". Since it is substantially less bright than the Photosphere, it can only be observed when the surface of the Sun is blocked out during a total solar eclipse.

View picture of Corona

The Corona is dominated by intense magnetic fields, around which the gas accumulates to create its beautiful and delicate structure. The temperature is even higher than that in the Chromosphere, climbing to some 3,000,000 degrees C. However, if an astronaut were to visit the corona and were somehow shielded from the direct rays of the Sun, he or she wouldn't roast to death - in fact, a spacesuit heating system would be required. This is because there simply isn't a lot of gas in the corona. In fact, the atmospheric pressure within the corona rivals laboratory work in creating an almost perfect vacuum.

There is enough energy in the corona to emit X-rays, however. An X-ray picture of the Sun taken from space quite clearly shows the corona.

View X-ray picture of Sun

Coronal holes are the source of great streams of solar matter that flow outward from the Sun. Termed the solar wind, these particles are continuously bombarding the Earth causing a wide variety of geophysical phenomena (such as aurorae or reduced radio reception).

1.4 Solar Activity

Under even casual inspection, the Sun appears as anything but a featureless yellow disk. There are a variety of things to see - some of which can even be observed with the naked eye. However, all solar observations must be done with extreme caution. See Observing the Sun safely for further information.

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 Sunspots
 ========
 View Picture 1 (close-up view of a sunspot group)
 View Picture 2 (full disk of Sun with sunspots)
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First detected by Galileo, sunspots are perhaps the most well known solar feature. Where strong magnetic fields intersect with the Photosphere, the temperature of the surrounding gas can be lowered from 5500 degrees C to 4500 degrees C. Because of this, sunspots appear dark when viewed against the background of the much brighter Sun.

A typical sunspot may have a diameter of more than 30,000 km (a few planets the size of the Earth could easily fit within one). Most consist of two parts. The inner region, called the umbra, is the darker of the two, and can reach 13,000 km in diameter. The outer region, known as the penumbra, is somewhat lighter in color. Some sunspots have no clearly defined penumbra because of their smaller size.

The life of a sunspot can range from a few hours to several months. Those sunspots which last longer can often be observed for several solar rotations, and can be used to provide a rough verification of the differential rotation of the Sun with different latitudes.

```
 Granulation
 ===========
 View Picture
```

As mentioned in The Sun - Structure and Nuclear Processes, granulation may also be observed on the Sun. Due to convective currents in the Convection Zone of the Sun, hot material from within is constantly being interchanged with cooler material at the surface. The resulting appearance of the solar disk is granulation.

```
 Spicules
 ========
```

Spicules are structures present in the Chromosphere of the Sun. These streams of gas shoot up from the Photosphere and can be 800 kilometers thick, up to 15,000 kilometers high, and last for up to 15 minutes.

```
 Flares
 ======
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Usually associated with sunspots, flares are huge eruptions taking place on the Sun. They are observed as an increase in brightness on the solar surface, and often give rise to intense bursts of electromagnetic radiation.

The following plot contains a representation of such an event. The data was recorded with the solar radio telescope at the Dominion Radio Astrophysical Observatory in Penticton, BC, Canada on April 1, 1992. The flare can be seen to begin at around 17:30 UT, reach a maximum of about 200 solar flux units above the baseline, quickly decrease from its maximum, then take several hours to return to its original, pre-flare level.

View plot of solar flare radio emissions

Coronal Mass ejections
======================

Periodically, changes in the Sun’s magnetic field trigger the ejection of billions of tons of gas from the corona. About 30% of the gas travels faster than the solar wind, reaching velocities of up to 2000 km/sec. If this gas reaches the Earth, a magnetic storm ensues.

These magnetic storms can affect the ionosphere of the Earth, resulting in a disruption of telecommunications. Sometimes, compass needles are affected and vast power outages occur. In the more northern or southern regions, the storms often create spectacular aurorae. During periods of high solar activity, the Earth intercepts about 70 coronal mass ejections per year.

Magnetic storms on the Earth were previously attributed to solar flares. This mistaken relationship arose since flares are much brighter, and often occur at the same time as coronal mass ejections. However, astronomer Jack Gosling, of the Los Alamos National Laboratory presented evidence to the December, 1993 meeting of the American Geophysical Union indicating the relationship with coronal mass ejections.

Prominences & Filaments
=======================

View Picture 1 - Prominence on solar limb
View Picture 2 - Filaments on solar disk, seen in H-alpha light

Gas suspended above the solar Photosphere by the Sun’s magnetic field is termed a "prominence" if the gas is visible at the limb of the Sun, and a "filament" if the gas is seen against the solar disk as a background. Since filaments are not as bright as the rest of the Sun, they appear as dark, snakelike features.

Viewing prominences or filaments requires a H-alpha filter with a bandwidth of 3 or 4 angstroms. A filter passing a band of less than 1 angstrom is required to see filaments on the solar disk.

1.5 The Solar Wind

In addition to heat and light, the Sun also emits a continuous low density stream of charged particles (mostly electrons and protons). Such a phenomenon was long suspected by scientists, but first confirmed from data returned by the Mariner 2 space probe. These particles are known as the "solar wind", and travel away from the Sun at approximately 450 km/sec (1,620,000 km/hour) in equatorial regions. Recent data from the Ulysses spacecraft seems to indicate that the solar wind originating from the south solar pole flows at nearly double the rate (750 km/sec) while differing somewhat in composition.

The solar wind and higher energy particles released from the Sun during coronal mass ejections combine to have strong effects on the Earth, ranging from aurorae to power line surges to radio interference. Due to the relatively slow speed of the solar wind (as compared to the speed of light at 299,792.458 km/sec), the effects are often felt a few days after an event is observed visually or by radio telescopes.

The following plot contains a representation of such an event. The data was recorded with the solar radio telescope at the Dominion Radio Astrophysical Observatory in Penticton, BC, Canada on April 1, 1992. The flare can be seen to begin at around 17:30 UT, reach a maximum of about 200 solar flux units above the baseline, quickly decrease from its maximum, then take several hours to return to its original, pre-flare level.

View plot of solar flare radio emissions

The solar wind is believed to originate within "coronal holes" - regions of the corona less dense and cooler than surrounding areas. It has been observed by the Voyager and Pioneer spacecraft to exist at least as far as the orbit of Pluto.

1.6 Helioseismology

Since the Sun is basically just a ball of hot gas, its interior transmits sound very well. In studying doppler shifts in the solar spectrum, the discovery of propagating sound waves in the Sun was made as long ago as 1962. It was noticed that certain parts of the Sun appeared to be receding while other parts were approaching. Five minutes or so later, the roles would reverse. This led scientists to the conclusion that the Sun was "pulsating" at a particular set of frequencies.

It is generally believed that convection near the surface of the Sun results in vigorous turbulent flows that produce a broad spectrum of random acoustical noise. Most of this noise is generated at approximately 0.003 Hz - far below the human ear’s limit of 20 Hz. Although sound is generated at a wide range of frequencies, the shape of the Sun forms a spherical resonator. The net result can be likened to a bell ringing at a particular frequency, even when hit by a clapper at random intervals.

The precise frequencies at which the Sun resonates can be used to determine the thermodynamic and compositional state of the material within, in much the same way as geologists use seismic readings to deduce the nature of the Earth’s interior.

Evidence obtained between 1977 and 1989 seem to indicate that the primary frequency of the Sun’s resonation changes with the current point in the solar cycle. When the Sun is less active, the frequency is a bit less than otherwise.

In the March 1995 issue of the "Astronomical Journal", astronomers reported evidence of similar resonations in observations of Eta Boötes.

1.7 The Solar Cycle

The Sun’s activity is not entirely constant. Between 1826 and 1843, the German astronomer Heinrich Schwabe produced evidence to indicate that sunspot activity tended to follow an approximate 11 year cycle. From a minimal number of sunspots, it took approximately four years to reach a peak of activity, then about seven years to fall to a new minimum. Later it was discovered that after every cycle of activity, the magnetic polarity of the sunspots was reversed. This suggested the existence of a 22 year cycle. In addition, the data seems to suggest an additional period of around 80 years.

In the last 100 years, the period of rise has ranged between 3.3 to 5.0 years, and the period of fall between 5.7 to 8.3 years, so it is difficult to make predictions about solar activity over any length of time.

At the beginning of each cycle (near minimum activity), sunspots occur in the higher latitudes of the Sun (about 40 degrees from the equator), gradually appearing nearer and nearer to the equator as the cycle progresses.

The number of visible sunspots is not the only indicator of solar activity that seems to follow an 11 year cycle. Radio emissions at a wavelength of 10.7 cm also confirm the pattern. There may also be some evidence that the weather on the Earth may follow a similar cycle. From 1645 to 1717, hardly any sunspots were recorded. This period was known as the "Maunder Minimum". Coinciding with the decrease in sunspots, the average temperature on the Earth fell, and particularly severe winters occurred in Europe.

In addition, studies published by Eigil Friis-Christensen and Knud Lassen of the Danish Meteorological Institute in Copenhagen in the November 1, 1991 issue of "Science" suggest another link between the solar cycle and climate conditions on Earth. They presented data which indicates a surprisingly strong relationship between the length of the solar cycle and the average temperature of the Earth’s atmosphere. Warmer temperatures seem to occur during shorter solar cycles.

1.8 Observing the Sun safely

It is likely that everyone has heard time and time again of the dangers of looking directly at the Sun. But such a warning bears repetition: on countless occasions, permanent blindness has been known to occur to individuals who do not use proper methods of solar observation. There are several safe ways to view the Sun which will be described here, but please ensure that you fully understand the technique before you risk your eyesight.

Projection
==========

The safest way to study the Sun is to not look at it directly at all. You can use a telescope or pair of binoculars to project an image of the Sun onto a piece of cardboard. ENSURE THAT YOU NEVER LOOK THROUGH THE TELESCOPE OR BINOCULARS AT THE SUN. EVEN A FRACTION OF A SECOND WILL PERMANENTLY BLIND YOU.

If you are using a pair of binoculars, cover one of the larger lenses first - you will only need to use one side of the binoculars. Likewise, if you are using a telescope with a finder scope, ensure that the finder is capped. Next, aim the telescope or binoculars roughly at the Sun (again, ensure that you do not look through the instrument to find the Sun). You will find it easy to line the instrument up with the Sun by moving it around until its shadows are as small as possible.

If you set up a piece of cardboard behind the telescope (on the same side of the telescope as the eyepiece), and line the telescope up well, you will see the image of the Sun projected onto the cardboard. You may have to adjust the focusing knob to get a clear image. Experiment with moving the cardboard nearer to or further from the eyepiece to get a smaller or larger image until you have the result you want.

The projection method is more than adequate to allow you to view and chart the movement of sunspots across the solar disk. One improvement you may wish to make is to use another piece of cardboard to make a large "collar" around the eyepiece of your instrument. If positioned properly, this collar will create a shadow on the cardboard you are using as a projection screen, making your image appear brighter and with higher contrast.

The projection method has the additional advantage that several people may observe the Sun at the same time. Just ensure you understand that the Sun's rays are being intensely concentrated by the lenses in the telescope or binoculars to a point just a few millimeters behind the eyepiece. Do not put anything near the eyepiece that you wish to keep (especially your eyes!). It will burst into flame almost immediately.

Filters
=======

Another method of viewing the Sun is with the use of the appropriate filters. Only use filters designed for this particular purpose - dark sunglasses and the like will NOT work and will be dangerous. You should be able to find companies advertising their solar filters for sale in reputable magazines such as "Sky & Telescope" or "Astronomy".

There are two places where filters can be used in a telescope - at the objective (or large lens), and at the eyepiece (the smaller lens). It is strongly recommended that you never use a filter at the eyepiece (and in my opinion, such filters should be banned). Eyepiece filters are dangerous in that they are placed right where the light is being concentrated the most. As a result, they can tend to heat up and crack without warning - blinding you instantly if you happen to be looking through the eyepiece at the time. If you really must use an eyepiece filter, ensure that you never keep the telescope pointed at the Sun for more than a few minutes. As well, if you use a larger telescope, construct a cardboard shield over the front of the instrument to prevent most of the light from entering. This will hopefully keep the filter cool enough to prevent cracking.

A much safer alternative is to use filters that fit over the objective of your telescope. With such a filter, you can observe the Sun all day if you want to - the filter doesn't warm up any more than the air around it. Of course, ensure that the filter is securely attached to the telescope. You wouldn't want a sudden gust of wind to pull it off, letting unfiltered light through the telescope.

If you wish to observe filaments or prominences, you will need a special filter called an H-alpha, or Hydrogen-alpha filter. This filter only allows one particular wavelength of hydrogen to pass through, enabling you to see details clearly.

1.9 Solar Eclipses

NOTE: For any attempts at solar eclipse viewing, it is essential that you read the section entitled Observing the Sun safely.

There are several different classifications of solar eclipses:

Total
=====
View Picture

The Sun is about 400 times larger than the Moon, and about 400 times further away. As a result, it appears about the same size in the sky. However, the Earth revolves around the Sun, and the Moon revolves around the Earth in slightly elliptical orbits. The result is that the distances to these objects changes slightly with time. Sometimes the Sun appears slightly larger than the Moon, and sometimes the Moon appears slightly larger than the Sun. It is in the latter case that a total eclipse is possible.

If the Moon passes directly between the Sun and your physical location on the Earth, and appears slightly larger than the Sun, you will see a total solar eclipse. For the few minutes of "totality", the Moon will appear to completely cover the disk of the Sun.

In the hours before the moment of maximum eclipse, the Moon can be observed to slowly obscure the Sun. A few minutes before totality, the total amount of light from the photosphere is reduced to the point that the blinking reflex that normally protects our eyes from the Sun's light no longer works. This is considered the most dangerous part of an eclipse, since people are tempted to stare at the Sun, even though it is still perfectly capable of damaging their eyesight.

Immediately before totality begins, brilliant points of light can be observed on the edge of the Sun. Known as "Baily's beads", these are the last bits of sunlight shining through valleys on the edge of the Moon. When the last "Baily's bead" is visible before totality, the appearance is often called the "diamond ring" effect. 3 to 5 seconds later, it too is obscured by the Moon. For another few seconds, the pink chromosphere is visible, as well as any prominences that may be there. Then totality begins.

During totality, you can see the corona of the Sun. It always surrounds the Sun, but since it shines a million times dimmer than the Sun itself, it is only visible when the Sun is in a dark sky - in other words, only during a total solar eclipse. During this phase of an eclipse (and ONLY during this phase), you can look directly at the Sun, without filters, as the corona is only about as bright as the full Moon.

During totality, the sky is as dark as it is during evening twilight. If you look toward the horizon in any direction, you can see beyond the darkest part of the moon's shadow. The result is a pinkish glow looking like a sunset extending completely around the horizon.

Though the length of totality varies depending on your location and the particular eclipse being observed, it will never last longer than about 7 minutes. Before it ends, you must stop looking directly at the Sun. The sequence of events following totality mirror those which led up to the event.

Annular
=======
When the Moon moves directly between the Sun and your physical location on Earth, but appears slightly smaller than the Sun, it will not be able to completely cover the Sun and cause a total eclipse. At the moment of maximum eclipse, an "annulus" or ring of the Sun around the Moon can be observed.

At no point during an annular eclipse is it safe to look at the Sun without protective filters.

Partial
=======
When the Moon only appears to partially cover the Sun from your physical location on Earth, the eclipse is said to be partial. Since the Moon appears as almost the exact same size as the Sun, only a narrow band along the Earth falls within its shadow and can observe a particular solar eclipse as being total. Most of the remainder of the Earth must be content with viewing a partial eclipse.

As with an annular eclipse, it is never safe to observe a partial eclipse of the Sun without protective filters.

See also: Eclipse Details: Solar Eclipse

1.10 The Sun - Exploration

The Sun has been the object of study for several interplanetary spacecraft. A chronological list of some of these probes, sorted by launch date, follows:

```
  Pioneer 6   - Dec. 16/65
  Pioneer 7   - Aug. 17/66
  Pioneer 8   - Dec. 13/67
  Pioneer 9   - Nov.  8/68
  Pioneer E   - Aug. 27/69
  Explorer 49 - Jun. 10/73
  Helios 1    - Dec. 10/74
  Helios 2    - Jan. 15/76
  Ulysses     - Oct.  6/90
```

1.11 The Sun - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

```
White light image, showing limb darkening & sunspots
Hydrogen-alpha image, showing filaments
X-ray image, showing activity in the corona
Image of the corona, during a total solar eclipse
Granulation on the surface of the Sun
Close up view of sunspots
Image of a prominence taken in Hydrogen-alpha light
View plot of solar flare radio emissions
```

1.12 Mercury - Fast Facts

```
Physical Characteristics
------------------------
Mass.............................3.3022e23 kg  (0.0553 times that of Earth)
Equatorial radius....................2439.7 km  (0.3825 times that of Earth)
Surface gravity........................2.78 m/s^2 (0.28 times that of Earth)
Escape velocity........................4.30 km/s
Apparent semidiameter at 1 AU..........3.36 arcseconds
Average density........................5.44 g/cm^3
Maximum surface temperature.............430 degrees C
Average surface temperature.............179 degrees C
Minimum surface temperature............-185 degrees C
Magnitude at 1 AU.....................-0.36
Geometric Albedo......................0.106
Largest surface feature...............Caloris Basin (1350 km diameter)
Surface composition...................Basaltic rocks
                                      Anorthositic rocks
                                      Regolith

Atmospheric Composition (by number of atoms):
    Helium..............................42%
    Sodium..............................42%
    Oxygen..............................15%
    Others...............................1%

Number of known satellites................0


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..........58.6462 days
Inclination of equator to orbit.........0.0 degrees
Orbital period (length of year)......87.967 days
Average orbital velocity............47.8725 km/sec.
Eccentricity...................0.2056317524914
Inclination of orbit to ecliptic...7.004986 degrees
Distance from Sun:
  Shortest..................... 46,001,000 km (0.30750 AU)
  Average...................... 57,909,000 km (0.38709 AU)
  Greatest..................... 69,817,000 km (0.46670 AU)
```

1.13 Mercury - Mythology

Mercury is named after the Roman god of roads and travel. He was also known as the god of commerce and wealth, and was a messenger of the gods. Thought to be deceptive, a trickster, and a thief, criminals considered him to be their protector.

Mercury was said to wear winged sandals (known as ‘talaria’) to enable him to deliver his messages quickly. He was also depicted as wearing a winged hat (‘petasus’) and carried a winged staff (‘caduceus’), with snakes intertwined around it to protect him on his travels. This staff later became adopted by the medical profession as their symbol.

Mercury was the son of Jupiter, the king of the gods, and Maia, a minor goddess.

It is believed that the planet received its name from this winged messenger because of its rapid movement across the sky.

1.14 Mercury - Discovery

Mercury has been known since at least the time of the Sumerians (3rd millennium BC). The Greeks had two names for it: ‘Apollo’ when it appeared in the morning sky, and ‘Hermes’ when it appeared in the evening sky, even though they knew that the two names referred to the same object.

The Greek philosopher Heraclitus (500 BC) correctly thought that Mercury moved around the Sun instead of the Earth.

1.15 Mercury - Exploration

Throughout the history of space exploration thus far, Mercury has been studied by only one spacecraft, Mariner 10. Mercury was revealed to be a heavily cratered planet, with a mass much greater than previously thought.

The trajectory of Mariner 10 allowed it to pass within 750 km of Mercury on March 29, 1974, 48,000 km on September 21, 1974, and 300 km on March 16, 1975. During these passes, approximately 45% of the planet’s surface was mapped.

Mariner 10 detected an extremely tenuous atmosphere around Mercury. Its density is only a few billionths that of the Earth’s atmosphere. Helium, one of the major constituents of Mercury’s atmosphere, must be continually replaced, as the surface gravity is too weak to retain it for very long.

In addition, Mercury was discovered to have a magnetic field about 1% as strong as that of the Earth. Despite its relative weakness, it is much stronger than astronomers suspected. It is thought that magnetic fields are produced by the rapid rotation of a molten iron core inside a planet. Mercury is believed to have an iron core making up 75% of the planet, however its slow rotation (once every 59 days) should produce a magnetic field much weaker than that observed.

The following picture is a mosaic of images taken from the Mariner 10 spacecraft. Two hemispheres are visible, but as they are not exactly opposite hemispheres, they cannot be joined to produce a view of one side of the globe.

View Picture

1.16 Mercury - A Strange Orbit

Mercury’s orbit is highly eccentric. At perihelion, it is only 46,001,000 km from the Sun, while at aphelion it is as much as 69,817,000 km. In addition, a rather strange phenomenon occurs with the orbit of Mercury: the perihelion of its orbit "precesses" around the Sun at a slow rate. In other words, the point in space at which Mercury makes its closest approach to the Sun changes with time. 19th century astronomers were unable to explain this effect using classical Newtonian mechanics, so they postulated that another planet (called Vulcan) might orbit near Mercury causing the observed changes. The true answer ended up being much more exciting: Einstein’s Theory of Relativity. It turned out that relativity predicted such an anomaly in the motion of Mercury, and in fact this prediction was an important factor in the early acceptance of the theory.

1.17 Mercury - The length of its day

The Earth’s moon is said to undergo "synchronous rotation". In other words, the Moon rotates around its axis in the same amount of time that it takes to go around the Earth, and as a result, the same side of the Moon always faces the Earth. For a long time, it was thought that a similar effect occurred with Mercury - with a Mercurian day and year being equal at 88 Earth days. However in 1965, radar observations of the planet proved this to be false. The length of Mercury’s day is only 59 Earth days. It still exhibits "synchronous rotation" of a sort, in that it rotates 3 times in 2 of its years. But this ratio is somewhat more complex than that of 1:1 exhibited by the Moon in its orbit around the Earth.

Because of this fact and the high eccentricity of Mercury’s orbit around the Sun, an observer on the surface would see a rather strange motion of the Sun across the sky. At some longitudes, the Sun would be seen to rise, gradually appearing to increase in size until it reaches the zenith. Then, the Sun would stop, briefly reverse course, stop again, and continue down to the opposite horizon, decreasing in size until it set. At other longitudes, a different but equally interesting motion would be observed.

1.18 Mercury - Physical Features

View Mosaic of two hemispheres

In many ways, Mercury is similar to the Earth’s moon. It is heavily cratered and has virtually no atmosphere. On the other hand, it is much denser than the Moon. This suggests that Mercury has a rather large iron core. In fact, it is larger than the Earth’s and is believed to comprise 75% of the planet. As a result, the silicate mantle and crust is believed to be relatively thin. In addition, recent data from radio telescope observations of the planet seem to indicate that Mercury's surface is poorer in titanium- and iron-bearing minerals than the Moon.

The larger craters on Mercury are well preserved and thought to be between 3 and 4 billion years old. This indicates that plate tectonics as we observe on Earth do not occur on Mercury.

There are numerous escarpments visible on the surface of Mercury. Some are over hundreds of kilometers in length and three kilometers high. It is believed that these escarpments were caused by the shrinking of Mercury by about 1 km in radius.

One of the largest features on the surface is the Caloris Basin - about 1350 km in diameter. It is thought to be similar to the maria on the Moon, and was probably caused by a very large impact early in the history of the solar system. On the exact opposite side of the planet, rather hilly terrain is observed (View picture). It is believed that the shock wave caused by the impact of the object producing the Caloris Basin was reflected and focused to this point, jumbling the crust and breaking it into a series of complex blocks.

In addition to the heavily cratered and hilly terrain, there are a few regions of relatively smooth plains. Though scientists are not sure what processes are responsible for these features, it is thought that they may be the result of ancient volcanic activity.

Radar observations of Mercury's polar regions in 1991 suggested that water ice several metres thick may exist at the bottom of some craters. Despite the fact that Mercury is so hot, some crater interiors are never exposed to direct sunlight. Ironically, Mercury may be the only inner planet where ice can be found dating back to the early history of the solar system. Unfortunately, the Mariner 10 probe did not take pictures of this region, so scientists are planning a future spacecraft to investigate the discovery.

1.19 Mercury - Observing the Planet

Because Mercury's orbit is inside that of the Earth, it is never seen far from the Sun in the sky. As a result it can only be seen with the naked eye when it is at one of its "Greatest Elongations" - when it is as far from the Sun as possible. Even then, it is difficult to see and is always glimpsed near to the horizon.

In a small telescope, Mercury can be seen to have a small disk 5 to 10 arcseconds in diameter. Like the Moon, Mercury can be seen to go through "phases". Mercury appears "full" at superior conjunction and "new" at inferior conjunction.

1.20 Mercury - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

```
Mosaic of two hemispheres
Closer view of Mercurian surface
```

1.21 Venus - Fast Facts

```
Physical Characteristics
------------------------
Mass..............................4.8690e24 kg  (0.8150 times that of Earth)
Equatorial radius....................6051.9 km  (0.9489 times that of Earth)
Surface gravity.......................8.87 m/s^2 (0.90 times that of Earth)
Escape velocity.......................10.4 km/s
Apparent semidiameter at 1 AU..........8.41 arcseconds
Average density.......................5.25 g/cm^3
Average surface temperature.............453 degrees C
Magnitude at 1 AU.....................-4.29
Geometric Albedo......................0.65
Highest surface feature................Maxwell Montes
                              (17 km above average planetary radius)
Surface composition....................Basaltic rocks

Atmospheric Composition (by number of atoms):
    Carbon dioxide......................96%
    Nitrogen............................3%
    Others (Water vapour, sulfur dioxide,
            carbon monoxide, hydrogen
            chloride, hydrogen fluoride,
            helium, argon, neon)..........1%

Atmospheric pressure.....................92 times that of Earth

Number of known satellites................0


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..........-243.01 days (*)
Inclination of equator to orbit.......177.3 degrees (*)
Orbital period (length of year).....224.695 days
Average orbital velocity............35.0214 km/sec.
Eccentricity...................0.0067718819142
Inclination of orbit to ecliptic...3.394466 degrees
Distance from Sun:
  Shortest.....................107,476,000 km (0.71843 AU)
  Average......................108,209,000 km (0.72333 AU)
  Greatest.....................108,941,000 km (0.72823 AU)
* Venus rotates in a retrograde direction.  In order to keep to the convention
of an object rotating counterclockwise about its axis, the inclination is
"flipped" around to 177.3 degrees.  If preferred, it may be specified as 2.7
degrees if the retrograde rotation is kept in mind.  Likewise, the rotation
period is specified as a negative number of days.
```

1.22 Venus - Mythology

Venus is named for the Roman goddess of love and beauty. It is believed that the name was chosen since it is the brightest of the planets.

Venus was the mother of Cupid (the Roman god of love) and Aeneas (an ancestor of the legendary founders of Rome). Originally symbolizing love and beauty, she later became known for the creative force that sustains all life. Venus closely resembles the Greek goddess Aphrodite.

Born full-grown from the foam of the Mediterranean Sea, Venus married Vulcan, a lame and ugly blacksmith god. She also fell in love with Mars, the god of war, and Adonis, a mortal.

In a myth called "The Judgment of Paris", Venus and the goddesses Minerva and Juno all claimed a golden apple - a prize which was reserved for the most beautiful goddess. In an attempt to settle the argument, Jupiter ordered Paris, the son of King Priam of Troy, to choose the most beautiful among them. When he chose Venus, Juno and Minerva became revengeful and ensured that Troy was destroyed in the Trojan War.

1.23 Venus - Discovery

Venus is a rather conspicuous object in the night sky, and has been known since prehistoric times. Like Mercury, Venus was given two names by the Greeks: ‘Phosphorus’ when it appeared in the morning sky, and ‘Hesperus’ when it appeared in the evening. Though they initially thought that Phosphorus and Hesperus were two separate objects, they later realized that the names referred to the same body. It was then named Venus in honor of the Roman goddess of love and beauty.

The Greek philosopher Heraclitus (500 BC) correctly thought that Venus moved around the Sun instead of the Earth.

1.24 Venus - Exploration

Venus has the distinction of being the most visited planet in the solar system. Ever since 1961, we have sent unmanned probes to explore this "sister planet" of the Earth. A chronological list of these probes, sorted by launch date, follows:

```
  Sputnik 7   - Feb.  4/61
  Venera 1    - Feb. 12/61
  Mariner 1   - Jul. 22/62
  Unannounced - Aug. 25/62
  Mariner 2   - Aug. 27/62
  Unannounced - Sep.  1/62
  Unannounced - Sep. 12/62
  Kosmos 21   - Nov. 11/63
  Unannounced - Feb. 27/64
  Zond 1      - Apr.  2/64
  Unannounced - Mar.  4/64
  Kosmos 27   - Mar. 26/64
```

```
Zond 2      - Nov. 30/64
Venera 2    - Nov. 12/65
Venera 3    - Nov. 16/65
Kosmos 96   - Nov. 23/65
Venera 4    - Jun. 12/67
Mariner 5   - Jun. 14/67
Kosmos 167  - Jun. 17/67
Venera 5    - Jan.  5/69
Venera 6    - Jan. 10/69
Venera 7    - Aug. 17/70
Venera 8    - Mar. 27/72
Kosmos 482  - Mar. 31/72
Mariner 10  - Nov.  3/73
Venera 9    - Jun.  8/75
Venera 10   - Jun. 14/75
Pioneer 12  - May  20/78
Venera 11   - Sep.  9/78
Venera 12   - Sep. 14/78
Venera 13   - Oct. 30/81
Venera 14   - Nov.  4/81
Venera 15   - Jun.  2/83
Venera 16   - Jun.  7/83
Vega 1      - Dec. 15/84
Vega 2      - Dec. 21/84
Galileo     - Oct. 18/89
Magellan    - May   4/89
```

Though a detailed explanation is given for the discoveries of each individual probe, a summary of their findings follows.

Because Venus appears to be similar to the Earth when viewed through a telescope, it was thought that conditions below its dense clouds might be very Earthlike and even have some form of life. But the data returned by the probes indicate that nothing could really be further from the truth. The pressure of Venus' atmosphere at the surface is 90 times greater than that of our own atmosphere. It is the same pressure experienced 1 km below the surface of the Earth's oceans. Clouds of sulfuric acid, and a high concentration of carbon dioxide in the atmosphere have produced a runaway greenhouse effect on the surface. Though nearly twice as far from the Sun as Mercury, the temperature at the surface is in fact hotter (450\degree\ C---hot enough to melt lead).

It is expected that Venus may have once had large amounts of water like the Earth, but it has long since boiled away. Now, its surface consists of gently rolling terrain with a few broad depressions and highlands. Much of the surface is covered by lava flows, and there is evidence to suggest that some volcanoes on Venus are still active. Meteor craters are not as prevalent on Venus as on many of the other planets - probably because most meteors burn up on entering the thick atmosphere.

It appears as though the crust of Venus is stronger and thicker than was once assumed. There is no evidence of plate tectonics, as there is on the Earth. Instead, convection in the mantle of the planet produces stresses on the surface which seem to be relieved in relatively small regions. No magnetic field has been detected around Venus.

1.25 Venus - A Runaway Greenhouse Effect

From ground-based observations, Venus appears to be similar to the Earth. Until the first space probes started exploring the planet, a number of prominent individuals thought it possible that life might exist beneath the thick clouds. Science fiction writers never tired of describing a "tropical rainforest" climate with all kinds of strange creatures living on the surface.

But scientists were in for a surprise when data started arriving from the first probes. It was found that Venus is much less similar to the Earth than originally thought. After descending through clouds of sulfuric acid several kilometres thick, the atmospheric pressure rises to a point 90 times more intense than that of the Earth by the time the surface is reached. With an atmosphere composed of 96% carbon dioxide, Venus experiences a runaway greenhouse effect.

Prior to probe exploration, many astronomers thought that the thick clouds surrounding Venus reflected a great deal of the Sun’s energy, producing a surface temperature similar to that of the Earth, despite Venus’ orbit nearer to the Sun. However, they discovered that the clouds act as a sort of "one way energy gate". Heat energy manages to get to the surface with little impedance. But when it is reflected back, the wavelength of the energy increases and the clouds do not allow for its escape. Thus, the atmosphere of Venus acts as a huge greenhouse - and the resulting temperature, at 450 degrees C, is much higher than thought possible to support life.

1.26 Venus - Length of the Day

Venus rotates in a retrograde direction. In other words, Venus rotates clockwise when viewed from above its North Pole - opposite to that of the other planets. In addition, the day on Venus is extremely long - it takes 243 Earth-days to rotate once about its axis, making the Venusian day longer than its year (225 Earth-days). An observer on Venus would see the Sun rise in the west and set in the east.

1.27 Venus - Physical Features

Venera 9 had the distinction of being the first spacecraft to land on another planet and return pictures of its surface. Images from this and later spacecraft showed a rather broken landscape strewn with rocks 0.3 to 1 metre in size.

The pictures returned by the Venera probes appear to have been taken through a "fisheye" lens. This is an extreme wide angle, distorting the edges of the image substantially, but allowing more to be observed in a single frame. Thus, in Venera images, one can see the base of the spacecraft in the lower center region, and the horizon appearing curved at the far left and right edges.

View picture from Venera 13

Because the surface of Venus is hidden by its thick clouds, the only way to study features is to either drop probes to image the surface directly or to use radar techniques to create maps. The first probes to use radar were Venera 15 and Venera 16. The maps obtained from these spacecraft revealed far greater information on surface features than had been previously obtained. Scientists discovered a landscape apparently volcanic in origin, and with fewer craters than exist on the Earth or Moon.

On May 4, 1989, the Magellan spacecraft was launched. Its primary objective was to use radar to map the surface of Venus with far greater detail than that obtained with the Venera spacecraft. It confirmed the earlier discovery of the relative lack of smaller craters. Much of the surface is covered with lava flows, with several large shield volcanoes apparent. One such volcano, Maat Mons, was discovered to be active. There are two large highland areas - Ishtar Terra in the northern hemisphere, and Aphrodite Terra near the equator. Three large depressions are also evident; Atlanta Planitia, Guinever Planitia, and Lavinia Planitia.

One such image from Magellan is provided with "The Digital Universe". It shows a old lava flow, having originated from a volcanic caldera named "Ammavaru" (not in the scene).

View Picture

Scientists have pieced together all the data returned by Magellan to create a radar map of the entire surface. This data was used to create the view that one hemisphere of Venus would have if the obscuring clouds were not in the way.

View Picture

In analyzing the gravity data also returned by Magellan, geologists have reasoned that the interior of Venus is likely similar to that of the Earth, with an iron core 3000 km in radius and a rocky mantle occupying most of the remainder of the planet. However, the crust of Venus is somewhat thicker than that of the Earth. In addition, the forces from convection within the mantle of Venus are relieved at a number of small regions on the surface, instead of being concentrated at plate boundaries as in the case of the Earth.

1.28 Venus - Observing the Planet

Because Venus' orbit is inside that of the Earth, it never appears far from the Sun. Clouds perpetually cover the surface of the planet, as can be seen from this image taken by Pioneer Venus.

View cloud features of Venus It is quite unusual for features to be visible in the clouds.

Because of the high reflectivity of the clouds and the planet's relatively near distance to the Sun and the Earth, Venus is usually the brightest object in the sky (other than the Sun and the Moon), with a magnitude often exceeding -4.0. If you know where to look, Venus can even been seen in the middle of the day, provided that it is far enough from the Sun.

In a small telescope, Venus can be seen to go through "phases", just like the Moon. Venus appears "full" at superior conjunction and "new" at inferior conjunction.

On June 8, 2004 a rather rare event will occur. From some locations on the Earth, Venus will appear to transit the Sun. You can use "The Digital Universe" to see if the event will be visible from your location, and if so, calculate the moments of first and last contact with the Sun.

1.29 Venus - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

View of cloud features from Pioneer Venus
View of lava flow from Magellan
Magellan radar mosaic of one hemisphere
View of the surface, from Venera 13

1.30 Earth - Fast Facts

```
Physical Characteristics
------------------------
Mass...............................5.9742e24 kg
Equatorial radius...................6378.14 km
Polar radius........................6356.75 km
Surface gravity........................9.81 m/s^2
Escape velocity........................11.2 km/s
Apparent semidiameter at 1 AU...........8.86 arcseconds
Average density.......................5.515 g/cm^3
Average surface temperature.............14 degrees C
Magnitude at 1 AU.....................-3.86
Geometric Albedo......................0.367
Highest surface feature................Mount Everest
                                 (8.85 km above sea level)
Surface composition....................Basaltic rocks
                                        Granitic rock
                                        Altered materials

Atmospheric Composition (by number of atoms):
    Nitrogen............................78%
    Oxygen..............................21%
    Argon.............................0.93%
    Others (Hydrogen, helium, neon,
            krypton, xenon, ozone,
            methane, carbon dioxide,
            carbon monoxide, nitrous
            oxide, ammonia, hydrogen
            sulfide)..................0.07%

Atmospheric pressure................101.325 kPa at sea level

Number of known satellites................1
       The Moon
```

```
Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..........0.99726968 days
Inclination of equator to orbit.......23.45 degrees
Orbital period (length of year).....365.2421897 days
Average orbital velocity............29.7859 km/sec.
Eccentricity....................0.0167086171540
Inclination of orbit to ecliptic...0.0 degrees (by definition)
Distance from Sun:
  Shortest......................147,098,447 km (0.9832923836 AU)
  Average.......................149,598,023 km (1.0000010178 AU)
  Greatest......................152,097,599 km (1.0167096520 AU)
```

1.31 Earth - Structure

The Earth, like the other planets, is made up of a number of layers from the core to the surface. They can be classified as follows:

```
Depth (km)      Layer
----------      -----
    0-  30      Crust
   30- 400      Upper mantle
  400- 650      Transition region
  650-2890      Lower mantle
 2890-5150      Outer core
 5150-6378      Inner core
```

Starting at the center of the Earth we have the inner core. It is suspected that temperatures there may be as much as 7200 degrees C, actually hotter than the Sun. It is believed to consist of solid iron and nickel. Although the temperatures are more than high enough to melt both metals if they were at the surface, the immense pressure keeps them in solid form.

Above the inner core, the outer core may be found. The temperature there ranges from 5000 to 2200 degrees C. Despite cooler temperatures, the pressure is sufficiently decreased so that iron and nickel melt.

Continuing out towards the surface of our planet we find the lower mantle. Temperatures range from 2200 to around 1000 degrees C. It is composed primarily of melted silicon, magnesium, iron, calcium, and aluminum along with oxygen. We then go through a transition region to the upper mantle. The upper mantle is still in liquid form, but differs from the lower mantle in that its composition is primarily olivine and pyroxene (iron and magnesium silicates), with calcium and aluminum. By the time the crust is reached, the temperature has cooled to 870 degrees C.

The outermost layer of the Earth is termed the crust. The thickness of the crust varies from about 8 km under the oceans to 30 km under the continents. Convection currents from within the mantle create large forces pulling on the crust in different directions. These forces cause the crust to pull apart into huge "plates" slowly moving in different directions (typically at a velocity of a few centimeters per year). This is known as plate tectonics, and the Earth is the only known planet in which the process is currently active, though several other solar system bodies contain geological evidence that tectonic activity has occurred at some point in their past.

Geological activity (such as volcanoes and earthquakes) occurs frequently at these plate boundaries. There are three main classifications for boundaries. Spreading zones are those regions where the plates are slowly pulling apart. As they spread, new crust is formed by magma upwelling to fill the gap. These regions usually experience substantially less violent geological activity than the other two.

Subduction zones are the areas where two moving plates collide. This process creates mountain ranges, as one plate typically dives below the other. When the plate is low enough to melt, molten material often finds its way to the surface through volcanoes.

The third class of boundary are those where simple transverse motion occurs - one plate slips past the other. This in itself would not be particularly impressive except for the fact that periodically the two plates stick together. Pressure continues to build over years until there is finally enough to overcome the friction. The result is a massive release of energy felt as an earthquake. The San Andreas fault in California is an example of a transverse boundary.

Taken as a whole, the Earth's atomic composition (by mass) is:

```
 Iron............34.6%
 Oxygen..........29.5%
 Silicon.........15.2%
 Magnesium.......12.7%
 Nickel...........2.4%
 Sulfur...........1.9%
 Other............3.7%
```

Due to the protective atmospheric shield of the Earth, we are spared from a great many of the meteoritic impacts which crater most of the other bodies in our solar system. But nevertheless, such impacts do happen from time to time. The following picture shows the results of such a collision. The Manicouagan crater in Quebec, Canada, is one of the largest on Earth. Blasted out of the landscape 210 million years ago, the feature is approximately 100 km in diameter.

View shuttle image of Manicouagan crater

1.32 Earth - Atmosphere

The Earth's atmosphere is comprised of the following gases:

```
 Atmospheric Composition (by number of atoms):
    Nitrogen.............................78%
    Oxygen...............................21%
    Argon..............................0.93%
    Others (Hydrogen, helium, neon,
            krypton, xenon, ozone,
            methane, carbon dioxide,
            carbon monoxide, nitrous
            oxide, ammonia, hydrogen
            sulfide)...................0.07%
```

It is believed that there was a much higher concentration of carbon dioxide in the Earth's atmosphere billions of years ago when it was formed. However, since then, most of the carbon dioxide has been incorporated in carbonate rocks. Plate tectonics and biological processes are continuously adding carbon dioxide to the atmosphere to replace that which is lost.

The tiny amount of carbon dioxide in the atmosphere is very important, however. It maintains the Earth's temperature by means of a "greenhouse effect". Allowing the Sun's energy to pass through to the surface, longer reflected wavelengths are trapped - resulting in a warmer climate. It is estimated that without the greenhouse effect, the Earth's average temperature would be -21 degrees C instead of the 14 degrees C that we now enjoy. There is some current concern about man adding pollutants to the atmosphere to strengthen the greenhouse effect. This would raise the average temperature of the Earth and cause many side effects that we can only begin to imagine. See
Venus - A Runaway Greenhouse Effect for an example of what can go wrong.

Another important component of the Earth's atmosphere is ozone. Existing primarily in the upper atmosphere, this shields life on Earth from the Sun's harmful radiation. This protection is extremely delicate, however. Several chemicals released into the atmosphere by man's activities break down ozone, neutralizing its effectiveness. Since it takes quite a long time for ozone to build up by natural processes, there is considerable concern about the effects of damaging this shield.

1.33 Earth - Pictures

Though literally billions of pictures of the Earth have been taken, a few can suffice to help describe how the Earth appears as a planet. It has been said that the image of Earth as it appears from space has been perhaps one of the most powerful images since the invention of photography.

Image 1

This picture was taken from the Galileo spacecraft on its route to Jupiter. Though man has traveled to the Moon and back, only spacecraft have been able to see the Earth and Moon as they appear together.

View Picture

Image 2

This picture was taken by the Apollo 11 astronauts while on their way to the Moon. Africa and the Middle East are prominent features.

View Picture

Image 3

Apollo 8 - the first manned mission to orbit the Moon returned a famous picture of the Earth rising above the lunar landscape.

View Picture

Image 4

The following picture was taken from a space shuttle, and shows the massive

Manicouagan crater in Quebec, Canada. The result of a meteor impact 210 million years ago, the feature is approximately 100 km in diameter.

View Picture

1.34 The Moon - Fast Facts

```
Physical Characteristics
------------------------
Mass................................7.349e22 kg  (0.0123 times that of Earth)
Equatorial radius.......................1738 km  (0.0272 times that of Earth)
Surface gravity.........................1.62 m/s^2 (0.17 times that of Earth)
Escape velocity........................ 2.4 km/s
Apparent semidiameter at 1 AU...........2.42 arcseconds
Average density.........................3.34 g/cm^3
Minimum surface temperature.............-173 degrees C
Maximum surface temperature..............127 degrees C
Magnitude at 1 AU.......................0.21
Geometric Albedo........................0.12
Surface composition.....................Basaltic rocks
                                        Breccia

Atmosphere..............................Negligible

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...............27.322 days
Inclination of equator to orbit............6.68 degrees
Orbital period...........................27.322 days
Average orbital velocity...................1.03 km/sec.
Eccentricity........................0.054900489
Inclination of orbit to Earth equator..18.28 - 28.58 degrees
Distance from Earth:
  Shortest.........................363,300 km
  Average..........................384,400 km
  Greatest.........................405,500 km
```

1.35 The Moon - Exploration

The Earth’s moon is the only object in our solar system to which we have sent manned missions (the Apollo flights). In addition, more unmanned probes have visited the Moon than any other object. A chronological list of these probes and expeditions, sorted by launch date, follows:

```
Unannounced     - May   1/58
Unannounced     - Jun. 25/58
Able 1          - Aug. 17/58
Unannounced     - Sep. 24/58
Pioneer 1       - Oct. 11/58
Pioneer 2       - Nov.  8/58
Unannounced     - Nov. 15/58
Pioneer 3       - Dec.  6/58
```

```
Luna 1           - Jan.  2/59
Unannounced      - Jan.  9/59
Pioneer 4        - Mar.  3/59
Unannounced      - Jun. 16/59
Luna 2           - Sep. 12/59
Luna 3           - Oct.  4/59
Able 4           - Nov. 26/59
Unannounced      - Apr. 12/60
Able 5A          - Sep. 25/60
Able 5B          - Dec. 15/60
Ranger 3         - Jan. 26/62
Ranger 4         - Apr. 23/62
Ranger 5         - Oct. 18/62
Unannounced      - Jan.  4/63
Unannounced      - Feb.  3/63
Luna 4           - Apr.  2/63
Ranger 6         - Jan. 30/64
Unannounced      - Apr.  9/64
Ranger 7         - Jul. 28/64
Ranger 8         - Feb. 17/65
Kosmos 60        - Mar. 12/65
Ranger 9         - Mar. 21/65
Luna 5           - May   9/65
Luna 6           - Jun.  8/65
Zond 3           - Jul. 18/65
Luna 7           - Oct.  4/65
Luna 8           - Dec.  3/65
Luna 9           - Jan. 31/66
Kosmos 111       - Mar.  1/66
Luna 10          - Mar. 31/66
Surveyor 1       - Apr. 30/66
Explorer 33      - Jul.  1/66
Lunar Orbiter 1  - Aug. 10/66
Luna 11          - Aug. 24/66
Surveyor 2       - Sep. 20/66
Luna 12          - Oct. 22/66
Lunar Orbiter 2  - Nov.  6/66
Luna 13          - Dec. 21/66
Lunar Orbiter 3  - Feb.  5/67
Kosmos 146       - Mar. 10/67
Kosmos 154       - Apr.  8/67
Surveyor 3       - Apr. 17/67
Lunar Orbiter 4  - May   4/67
Explorer 35      - Jul. 19/67
Surveyor 4       - Jul. 14/67
Lunar Orbiter 5  - Aug.  1/67
Surveyor 5       - Sep.  8/67
Surveyor 6       - Nov.  7/67
Unannounced      - Nov. 22/67
Surveyor 7       - Jan.  7/68
Zond 4           - Mar.  2/68
Luna 14          - Apr.  7/68
Unannounced      - Apr. 22/68
Zond 5           - Sep. 14/68
Zond 6           - Nov. 10/68
Apollo 8         - Dec. 21/68
Unannounced      - Jan.  5/69
```

```
Unannounced     - Apr. 15/69
Apollo 10       - May  18/69
Unannounced     - Jun. 12/69
Luna 15         - Jul. 13/69
Apollo 11       - Jul. 16/69 (first manned mission)
Zond 7          - Aug.  8/69
Kosmos 300      - Sep. 23/69
Kosmos 305      - Oct. 22/69
Apollo 12       - Nov. 14/69
Unannounced     - Feb. 19/70
Apollo 13       - Apr. 11/70
Luna 16         - Sep. 12/70
Luna 17         - Nov. 10/70
Kosmos 382      - Dec.  2/70
Apollo 14       - Jan. 31/71
Apollo 15       - Jul. 26/71
Luna 18         - Sep.  2/71
Luna 19         - Sep. 28/71
Luna 20         - Feb. 14/72
Apollo 16       - Apr. 16/72
Apollo 17       - Dec.  7/72
Luna 21         - Jan.  8/73
Mariner 10      - Nov.  3/73
Luna 22         - May  29/74
Luna 23         - Oct. 28/74
Unannounced     - Oct. 13/75
Luna 24         - Aug.  9/76
Galileo         - Oct. 18/89
Hiten           - Jan, 1990
Clementine      - Jan. 25/94
```

1.36 The Moon - Features

A great deal of information about the Moon has been learned as a result of probes and expeditions. The Moon is the only body in the solar system (other than the Earth) to which men have traveled and returned samples.

The Moon has no atmosphere. Clementine, the most recent probe sent to the Moon, has yielded evidence which suggests that water ice may be present near the lunar poles. Though the evidence is inconclusive, such a discovery would be extremely important for the construction and maintenance of future manned bases on the Moon.

The Moon's crust varies in thickness from almost nothing beneath Mare Crisium to 107 km just north of the crater Korolev on the far side. Seismic experiments on the Moon measuring "moonquakes" have revealed that a mantle and core probably lie beneath the crust. From geochemical analysis of lunar rock samples in 1990, Horton E. Newsom of the University of New Mexico declared that he had found evidence that the Moon's core comprises approximately 5% of its total mass.

There are two main types of terrain on the Moon. Maria (which comprise 16% of the lunar surface) are huge craters which were flooded with molten lava. These are visible as the dark patches on the Moon, and are relatively recent features. In contrast to the maria, there are heavily cratered and mountainous regions which are significantly older. Most of the surface is covered with a mixture of fine dust and small rocks. This material, called "regolith", is likely produced from meteor impacts.

The various missions to the Moon have returned 382 kg of rock and dust from the lunar surface. Still being studied today, these samples have provided scientists and geologists with their most detailed knowledge about the Moon. They have dated the rocks at between 3 and 4.6 billion years old - which contrasts from the upper limit of 3 billion years old for rocks on Earth.

The Moon has no magnetic field. However, studies of some of the rocks on the surface of the Moon indicate that there may have been such a field billions of years ago. With no atmosphere or magnetic field, the Moon has no shielding from the solar wind. As a result, ions in the solar wind have been embedding themselves in the Moon’s regolith for a long time. Studies of the regolith give us clues about how the solar wind has been varying with time.

1.37 The Lunar day

The Moon is said to be in "synchronous orbit" with the Earth. Because the Moon is a bit more massive on one side, over billions of years its rotational period slowly changed until it became the same as its revolutional period. As a result, the Moon rotates around its own axis in the same amount of time it takes to go around the Earth, and thus more or less keeps one side of the Moon always facing the Earth. This side is usually referred to as the "near" side. Nobody had ever seen what the "far" side of the Moon looked like until spacecraft were sent to fly around the Moon and photograph its appearance.

However, the Moon’s orbit is slightly eccentric. As a result, it is sometimes a bit nearer to the Earth (and hence moves a bit faster) than at other times. Since the law of physics known as the "Conservation of Angular Momentum" states that the Moon’s spin about its own axis cannot speed up or slow down to keep pace with its changing velocity, the Moon cannot keep exactly the same side continually facing the Earth. As a result, the region facing the Earth varies slightly throughout the Moon’s orbit. The effect of this is to make the Moon appear to "wobble" slightly, revealing about 57% of the lunar surface to us instead of the 50% that would be revealed if the Moon did not appear to "wobble". This effect is known as libration, and it is used by "The Digital Universe" in determining the precise appearance of the Moon at any particular time.

The result of all these motions can be translated to how they would appear by an observer on the lunar surface. The movement of the Sun across the sky would not be too unusual. Though it would speed up and slow down slightly in its motion, the effect would not be that noticeable. The biggest difference would be that the lunar day would take about 29.5 Earth days to complete.

However, the appearance of the Earth would be an interesting phenomenon. Since the Moon basically keeps the same side directed to the Earth at all times, the position of the Earth would never seem to change that much. An observer on the near side of the Moon would see the Earth in essentially the same position of the sky for years on end, while an observer on the far side would never see the Earth at all. The only apparent motion of the Earth would be caused by libration, making it appear to slowly move slightly back and forth.

1.38 Phases of the Moon

One half of the Moon is always illuminated by the Sun. To observers on the Earth, the Moon appears to go through different phases because we see different fractions of the lighted half when the Moon is at different parts of its orbit.

When the Earth is located between the Sun and the Moon, we see the entire side of the Moon which is lit up. This phase is termed "full". Similarly, when the Moon is located between the Earth and the Sun, we observe the dark side of the Moon, since the Sun is lighting up the half of the Moon which we cannot see. We call this phase "new". Note that because the Moon orbits the Earth at a slight angle, the three bodies don't usually line up in a perfectly straight line. Usually one is a bit above or below the other. If the Moon does happen to line up directly between the Sun and the Earth, we lie in the shadow of the Moon, and a Solar Eclipse is said to occur. Likewise, if the Earth lies directly between the Moon and the Sun, the Moon lies in the shadow of the Earth. When this occurs, a "Lunar Eclipse" is said to occur and the Moon appears dark red despite the fact that it is "full".

Between the two extremes of "new" and "full" moon, the Moon goes through a full range of other phases. When the Moon appears less than half illuminated, we say it is a "crescent". When more than half illuminated, it is termed a "gibbous". When exactly half illuminated, it is simply called a "half moon".

In addition to these classifications, there are two other words which may be used to further refine the phase. When the illuminated portion of the Moon is growing larger, we say that the Moon is "waxing". When the illuminated portion is growing smaller, we say that the Moon is "waning".

All of this terminology leads us to come up with the following names for the various phases of the Moon, in the order in which they occur:

```
New Moon
Waxing Crescent
Waxing Half Moon (Usually called First Quarter)
Waxing Gibbous
Full Moon
Waning Gibbous
Waning Half Moon (Usually called Last Quarter)
Waning Crescent
New Moon
....
```

Waxing Half Moon is usually called First Quarter, since at that time the Moon is 1/4 the way through its cycle of phases. Likewise, Waning Half Moon is usually called Last Quarter, since at that time it is 3/4 the way through its cycle of phases.

Another concept helpful in describing the current phase of the Moon is that of its 'age'. In this context, age does not refer to how long ago the Moon was formed (which would be measured in billions of years), but rather how long ago it was that the Moon was New (measured in days). Thus, a New Moon can be referred to as having an age of 0 days, whereas a Full Moon will have an age of about 15 days (since the phases of the Moon repeat with an approximate 29.5 day period). By referring to the phase of the Moon by means of its 'age', one can be more accurate than just by referring to one of the eight basic phases. When you click on the Moon with "The Digital Universe", you are presented with information on both the current ‘age’ of the Moon, and when the Moon will enter (and has entered) its various basic phases.

An interesting point to note is that the dark portion of the Moon is never completely dark - it is just dark by comparison with the bright side. It is feebly lit up by "earthshine" - sunlight that bounces off the Earth and back up to the Moon. Often, earthshine is bright enough that the dark side of the Moon can be easily seen.

Since the cycle of phases repeats with a 29.5 day period, there is usually one cycle per month. Throughout history, farmers have developed unique names for the full moons in different months, as an aid to remembering the occurrence of events throughout the seasons. These names are not recognized by the astronomical community, but are provided here for interest’s sake:

```
  January     Wolf Moon
  February    Snow Moon
  March     Worm Moon
  April     Pink Moon
  May     Flower Moon
  June      Strawberry Moon
  July      Buck Moon
  August      Sturgeon Moon
  September   Harvest Moon
  October     Hunter’s Moon
  November    Beaver Moon
  December    Cold Moon
```

In all months except February (which is too short), two full moons are possible. It doesn’t happen often, but when it does, the second full moon can be termed a "Blue Moon".

View photos of various lunar phases

1.39 The Moon - Pictures & Audio clips

Though links to these pictures and audio clips occur in various places throughout the document, they are provided here as well for convenience.

```
 Pictures
 ========
 The Earth and Moon together
 Various phases of the Moon
 Earth rising over lunar surface
 Saturn V rocket
 Armstrong’s first steps on moon
 Apollo 11 LEM returning from moon
 Apollo 16 landing site

 Audio
 =====
 First words spoken from the Moon
 Armstrong sets foot on the Moon
```

1.40 Mars - Fast Facts

```
Physical Characteristics
------------------------
Mass...............................6.4191e23 kg  (0.1074 times that of Earth)
Equatorial radius.......................3397 km  (0.5326 times that of Earth)
Polar radius............................3375 km  (0.5309 times that of Earth)
Surface gravity.........................3.72 m/s^2 (0.38 times that of Earth)
Escape velocity.........................5.0 km/s
Apparent semidiameter at 1 AU...........4.72 arcseconds
Average density.........................3.94 g/cm^3
Minimum surface temperature............-140 degrees C
Average surface temperature.............-63 degrees C
Maximum surface temperature..............20 degrees C
Magnitude at 1 AU.....................-1.52
Geometric Albedo........................0.15
Highest surface feature.................Olympus Mons
                                (24 km above surrounding plains)
Surface composition.....................Basaltic rocks
                                        Altered materials

Atmospheric Composition (by number of atoms):
    Carbon dioxide.....................95.3%
    Nitrogen............................2.7%
    Argon...............................1.6%
    Oxygen.............................0.15%
    Water..............................0.03%
    Neon.............................0.0003%

Atmospheric pressure...................0.007 times that of Earth

Number of known satellites................2
       Phobos
       Deimos


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..........24.6229 hours
Inclination of equator to orbit.......25.19 degrees
Orbital period (length of year)......686.98 days
Average orbital velocity............24.1309 km/sec.
Eccentricity....................0.0934006199474
Inclination of orbit to ecliptic...1.849726 degrees
Distance from Sun:
  Shortest.....................206,650,000 km (1.38137 AU)
  Average......................227,939,000 km (1.52368 AU)
  Greatest.....................249,229,000 km (1.66599 AU)
```

1.41 Mars - Mythology

Mars is named for the Roman god of war. He was the son of Jupiter and the father of Romulus and Remus, the legendary founders of Rome. Originally, Mars was considered the god of farmland. As a result, the month of March, the beginning of the Roman growing season, was named after him.

Mars became known as the god of war when the Romans came into contact with the Greek culture and gave him characteristics of the Greek god Ares.

Mars had a love affair with Venus, the Roman goddess of love. It is believed that the planet inherited its name from the god of war since it appears a reddish color.

1.42 Mars - Discovery

As Mars is a rather bright object in the night sky, it has been known since prehistoric times. Of course, the ancients did not realize that Mars was a planet much like the Earth, but were fascinated by this bright red point of light that moved across the background sky from night to night.

1.43 Mars - Exploration

Through the telescope, Mars remains an elusive object. Patches and lines appearing on the surface have led several astronomers to wrongly suspect that they had detected irrigation canals and fields of vegetation. With the launch of several interplanetary probes, we have been able to have a good look at Mars. They reveal Mars to be a windswept and desolate place, with no signs of life ever having existed there.

A chronological list of these probes, sorted by launch date, follows:

```
  Unannounced     - Oct. 10/60
  Unannounced     - Oct. 14/60
  Unannounced     - Oct. 24/60
  Unannounced     - Oct. 24/62
  Mars 1          - Nov.  1/62
  Unannounced     - Nov.  4/62
  Mariner 3       - Nov.  5/64
  Mariner 4       - Nov. 28/64
  Unannounced     - Mar. 27/67
  Mariner 6       - Feb. 24/69
  Mariner 7       - Mar. 27/69
  Mars 1969A      - Mar. 27/69
  Mars 1969B      - Apr. 14/69
  Mariner 8       - May   8/71
  Kosmos 419      - May  10/71
  Mars 2          - May  19/71
  Mars 3          - May  28/71
  Mariner 9       - May  30/71
  Mars 4          - Jul. 21/73
  Mars 5          - Jul. 25/73
  Mars 6          - Aug.  5/73
  Mars 7          - Aug.  9/73
  Viking 1        - Aug. 20/75
  Viking 2        - Sep.  9/75
  Phobos 1        - Jul.  7/88
```

```
  Phobos 2          - Jul. 12/88
  Mars Observer     - Sep. 25/92
```

In addition, the following spacecraft are planned for the near future:

```
  Mars 96           - 1996
  Mars Surveyor     - Nov. 1996
  Mars Pathfinder   - Dec. 1996
  Mars 98           - 1998
```

1.44 Mars - Physical Features

Though Mars is smaller than the Earth, our oceans cover a great deal of our planet's surface. As a result, the total land area on the two planets is approximately the same. Some of the terrain on Mars is quite spectacular, some chief highlights being:

```
 Olympus Mons:      The largest known mountain in the entire solar system.
                    Its base is 500 km in diameter, and is 24 km high (3 times
                    higher than Mount Everest!).  Surrounding the mountain
                    is a cliff 6 km high.
                    View picture

 Tharsis:           A huge 'bulge' in the surface 4000 km across and 10 km
                    high.  Since Mars does not have plate tectonics like the
                    Earth, hot spots within the mantle stay at a fixed spot
                    relative to the crust.  It is suspected that such a hot
                    spot may be a possible cause for Tharsis.  In comparison,
                    as plates of the Earth's crust move about, different parts
                    of the crust appear over the hot spot at different times.
                    This motion results in the creation of features such
                    as the Hawaiian Island chain.

 Hellas Planitia:   This is an impact crater in the southern hemisphere
                    2000 km in diameter and 6 km deep.

 Valles Marineris:  A huge network of canyons.  They span an area 4000 km
                    long and are up to 7 km deep in places.  In comparison,
                    the Grand Canyon is only 400 km long, and is no deeper
                    than 2 km.  These canyons were not created by running
                    water at some time in Mars' history.  Instead, they
                    were formed by the crust stretching as Tharsis was
                    formed.
```

Most of the surface is old and cratered, but there are also a fair number of ridges, hills, and plains. The following picture, taken by the Viking 1 orbiter at latitude 10deg S, longitude 47 degrees shows some of these craters and cliffs.

View picture

The next picture is a mosaic of Viking images to convey the appearance that Mars would have from space. Schiaparelli crater (450 km in diameter) is located near the center of the image. In the south polar region at the far right corner, carbon dioxide frost can be seen.

View picture

In studying the multitude of images taken from spacecraft observing Mars, scientists have found clear evidence of erosion. It is quite likely that at some point in Mars' history, water existed on the surface in relative abundance. But this would have been long ago - the age of some of the erosion channels is estimated at about 4 billion years old.

Not all of the water on Mars has disappeared however. Mars has permanent ice caps at both poles. Admittedly, most of the ice is frozen carbon dioxide (dry ice) but in the northern summer, the carbon dioxide in the ice cap evaporates revealing a residual layer of water ice. It is suspected that such a layer exists in the southern polar cap as well, but since the carbon dioxide ice never completely disappears, this layer has never been revealed. It is hoped that future missions to Mars may confirm the existence of water ice in the south polar cap.

View picture of south polar ice cap

Based on infrared spectra obtained by Mariner 9, Viking 1, and Viking 2, astronomers David Paige, David Crisp, and Michelle Santee found that the cloud tops 30 km about Mars' north polar region are anomalously cold. Apparently, carbon dioxide is freezing and falling to the surface. It is expected that up to 3 millimeters of carbon dioxide snow falls daily onto Mars' north polar cap during the winter, accumulating up to a meter before spring arrives.

Some scientists also express the hope that water ice will be found below the surface of the planet in regions other than at the poles. Sometimes a 'muddy looking' flow can be seen to lead from an impact crater. It is thought that these may have been caused by a meteor melting a layer of ice beneath the surface.

The Viking probes both sent landers safely down to the surface to return images and data. However, color pictures of the surface suffer from some uncertainties - particularly with regards to the relative brightness of the red and blue channels. Owing to these calibration uncertainties, early reconstructions of the Viking images tended to show a blue sky, while later (more accurate) reconstructions revealed a more "reddish" sky and orange surface. Other image specialists tend to favour a more brownish tint to the surface. In truth, the exact colors of the sky and ground are not precisely known. Hopefully the problem is resolved with future spacecraft.

The following image shows a bit of the region arounding the Viking 2 landing site. Rocks in the image range in size up to about 1.5 metres. One of the landing pads is visible in the lower right corner, and the shroud that protected the soil collector head during the lander's descent is observed to have fallen off. In addition, the two scrape marks near the center of the image are not natural features - they were caused by robot arm in collecting samples of the surface.

View picture of Viking 2 landing site

At Viking 2's location, water frost is observed to collect on the ground in a thin layer during the winter.

View picture of Viking 2 landing site in winter

1.45 Is there life on Mars?

Science fiction writers of the past have loved to entertain the idea that life might exist on Mars. As early astronomers began to pay more and more attention to the red planet, the possibilities of life there started to look rather promising.

The first such evidence came from the Italian astronomer Schiaparelli. He observed bright and dark features on the surface of the planet, and suggested the existence of ‘canali’, or channels connecting the darker regions. These features were observed to change in size and shape throughout the Martian seasons and led many people to believe that life might exist on the planet. Three schools of thought existed:

1. The markings on the surface of Mars were nothing but natural, inorganic features. Any seasonal variations were due to winds blowing dust around, polar ice caps melting, etc.

2. The dark areas observed on the surface of the planet were some form of vegetation. The regions occupied by the vegetation were changed naturally by the seasons.

3. The dark areas were vegetation, tended by ‘Martians’. Some astronomers felt that as the polar ice caps began to melt in the summer, Martians transported the water to the more temperate growing regions via an immense network of canals.

The dispute remained largely unresolved until the first spacecraft began to visit the planet. Mariner 9 failed to see any artificially created canals, but did confirm that there was a small quantity of water on Mars, locked up in the ice of the polar caps. And then, the Viking 1 and Viking 2 probes were launched - their primary mission to determine whether life existed on Mars.

The Viking spacecraft consisted of orbiters that remained above the planet, and landers that descended safely to the surface. The findings were somewhat inconclusive. The atmosphere contained the right components believed necessary for life (though in the wrong proportions for human life). The chief problem was that Mars was simply too dry.

Each Viking lander had 5 instruments available to search for life, and these instruments were used in a series of experiments. One such experiment seemed to give positive results while two others were negative. Most scientists now think that the processes observed are not associated with any life processes but represent some new, unusual chemistry. But nevertheless, the studies were done in only two isolated locations on the Martian surface, and future exploration is highly desirable. It is not expected that we will ever find advanced forms of life on Mars, but life of any sort would prove that the Earth is not unique in this respect.

1.46 Mars - Observing the Planet

Because Mars’ orbit is outside that of the Earth, it does not go through a full cycle of phases as do the inner planets and the Earth’s moon. Instead, it always appears to be full or nearly full. Slight phases do exist, however, and in fact were first discovered by Galileo. They are most easily visible through a telescope when the phase angle is largest. "The Digital Universe" simulates the phase of Mars properly and will allow you to determine the best times for observing it.

In a large telescope, some dark markings on the surface can be seen. "The Digital Universe" simulates the appearance of these markings when zoomed in sufficiently to see the disk of the planet. Thus, observations at the telescope can be compared to those simulated with the software.

Periodically, dust storms occur on the surface of Mars. Sometimes these storms can grow in size until they virtually cover the entire planet. During such periods, Mars appears virtually featureless due to the high concentration of particles in its atmosphere.

1.47 Mars - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience. For images of Mars' moons, please follow the links to the satellite of interest, provided at the introductory screen for information on the planet.

```
Mosaic of Mars, centered on Schiaparelli crater
Martian craters and cliffs, imaged from orbit
Olympus Mons - largest mountain in the solar system
South polar ice cap (water & carbon dioxide ice)
View from the landing site of Viking 2, in summer
View from the landing site of Viking 2, in winter
```

1.48 Phobos - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.......................Asaph Hall
Date of Discovery......................1877
Alternate identification.............Mars I
Mass.................................1.08e16 kg  (1.81e-9 times that of Earth)
Dimensions...................27.0x21.6x18.8 km. (0.00212 times that of Earth)
Surface gravity.......................0.004 m/s^2 (4e-4  times that of Earth)
Escape velocity.......................0.011 km/s
Apparent semidiameter at 1 AU...........0.02 arcseconds
Average density.........................2.0 g/cm^3
Magnitude at 1 AU......................11.8
Geometric Albedo.......................0.06

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...............0.3189 days
Orbital period...........................0.3189 days
Average orbital velocity..................2.14 km/sec.
Eccentricity.............................0.015
```

```
Inclination of orbit to Mars' equator.......1.0 degrees
Distance from center of Mars:
  Shortest...........................9,237 km
  Average............................9,378 km
  Greatest...........................9,519 km
```

1.49 Phobos - Description

Phobos (pronounced FOH-bus) was discovered by Asaph Hall in 1877. It was named "Phobos" (meaning fear) after an attendant of the Roman god of war, Mars.

Phobos is an extremely small and dark moon orbiting Mars. It appears to be similar in composition to the carbonaceous chondrite asteroids found in the outer asteroid belt. As a result, some scientists believe that it may be an asteroid captured by Mars some time ago. Since Phobos has such a low density, many astronomers suspect that it is composed of a mixture of rock and ice.

One of the most prominent features on Phobos is a giant crater, named "Stickney" after the maiden name of Hall's wife. It, along with several grooves radiating from the crater, are visible in the image. It is likely that Phobos was nearly shattered by the force of collision.

Phobos is the smallest known moon in the solar system. In addition, Phobos orbits closer to its planet than any other moon, skimming less than 6,000 km from the planet's surface. Because of this proximity, tidal forces are pulling it towards Mars. It is predicted that in less than 100 million years, Phobos will either crash into the surface of Mars, or break up into a ring system orbiting the planet.

In 1989, the Russian spacecraft Phobos 2 detected a faint and steady stream of gas emanating from the moon. Though contact was lost with the probe before the gas could be analyzed, many scientists suspect that it may be water vapour.

Astronomers are anxious to determine if Phobos and Deimos contain water ice. If so, they will be particularly useful someday as natural space stations in orbit about Mars.

1.50 Deimos - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.......................Asaph Hall
Date of Discovery......................1877
Alternate identification............Mars II
Mass.............................. 1.8e15 kg  (3.0e-10 times that of Earth)
Dimensions..................15.0x12.2x11.0 km. (0.00118 times that of Earth)
Surface gravity.......................0.002 m/s^2 (2e-4  times that of Earth)
Escape velocity.......................0.059 km/s
Apparent semidiameter at 1 AU..........0.01 arcseconds
Average density.........................1.7 g/cm^3
Magnitude at 1 AU.....................12.89
Geometric Albedo.......................0.07
```

```
Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............1.2624 days
Orbital period..........................1.2624 days
Average orbital velocity..................1.36 km/sec.
Eccentricity............................0.0005
Inclination of orbit to Mars' equator...0.9-2.7 degrees
Distance from center of Mars:
  Shortest..........................23,447 km
  Average...........................23,459 km
  Greatest..........................23,471 km
```

1.51 Deimos - Description

Deimos (pronounced DEE-mus) was discovered by Asaph Hall in 1877. It was named "Deimos" (meaning terror) after an attendant of the Roman god of war, Mars.

Deimos is an extremely small and dark moon orbiting Mars. It appears to be similar in composition to the carbonaceous chondrite asteroids found in the outer asteroid belt. As a result, some scientists believe that it may be an asteroid captured by Mars some time ago. Since Deimos has such a low density, many astronomers suspect that it is composed of a mixture of rock and ice.

Though both Phobos and Deimos are covered with craters, Deimos has a somewhat smoother appearance. Many of its craters are partially filled in by some unknown mechanism.

Deimos is the second smallest known moon in the solar system. Only Phobos is smaller.

Astronomers are anxious to determine if Phobos and Deimos contain water ice. If so, they will be particularly useful someday as natural space stations in orbit about Mars.

1.52 Jupiter - Fast Facts

```
Physical Characteristics
------------------------
Mass..............................1.8988e27 kg  (317.83 times that of Earth)
Equatorial radius....................71492 km  (11.209 times that of Earth)
Polar radius.........................66854 km  (10.517 times that of Earth)
Surface gravity......................24.79 m/s^2 (2.53 times that of Earth)
Escape velocity.......................59.5 km/s
Apparent semidiameter at 1 AU.........99.31 arcseconds
Average density.......................1.31 g/cm^3
Average temperature at cloud tops.......-150 degrees C
Magnitude at 1 AU.....................-9.40
Geometric Albedo.......................0.52
Largest surface feature................Great Red Spot
```

```
                            (12000 x 25000 km - larger than two Earths)

 Composition (by number of atoms):
     Hydrogen............................90%
     Helium..............................10%
     Methane...........................0.07%
     Other (water, ammonia, 'rock').....Trace

 Number of known satellites................16
    Ganymede  Pasiphae
    Callisto  Metis
    Io        Carme
    Europa    Lysithea
    Amalthea  Sinope
    Himalia   Ananke
    Thebe     Adrastea
    Elara     Leda


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period, System I....9.842 hours
                             System II...9.928 hours
                             System III..9.925 hours
 Inclination of equator to orbit..........3.12 degrees
 Orbital period (length of year)........11.856 years
 Average orbital velocity..............13.0697 km/sec.
 Eccentricity.....................0.0484948512199
 Inclination of orbit to ecliptic.....1.303270 degrees
 Distance from Sun:
   Shortest.......................740,555,000 km (4.95030 AU)
   Average........................778,298,000 km (5.20260 AU)
   Greatest.......................816,041,000 km (5.45490 AU)
```

1.53 Jupiter - Mythology

Jupiter is named after the Roman king of the gods and ruler of the Universe. Sometimes called Jove, he is roughly equivalent to the Greek god Zeus.

Jupiter was the son of Saturn, who was considered the initial ruler of the Universe. His brothers were Neptune and Pluto, and his sisters were Ceres, Juno, and Vesta. Saturn's children overthrew him, and Jupiter took his place. Jupiter then married Juno, who became queen of the gods.

Jupiter and Juno had Mars and Vulcan as children. But Jupiter was unfaithful to Juno and had many mistresses. Some of his other children included Apollo, Bacchus, Mercury, Diana, and Hercules.

Jupiter is usually portrayed as an extremely dignified and majestic bearded man.

1.54 Jupiter - Discovery

Jupiter is the fourth brightest object in the sky, being outshined only by The Sun, The Moon, and Venus. As a result, it has been known since prehistoric times. Of course, the ancients did not realize that Jupiter was a planet much larger than the Earth, but its motion across the background sky remained a fascination.

In 1610, Galileo was greatly surprised to see four bright "stars" remaining near the planet in its path through the sky. He didn't know what they were, but named them the "Medicean stars", after the Medici family who ruled the province of Tuscany, where he was born. Later, astronomers realized that these stars were in fact moons revolving around Jupiter. Galileo had unknowingly discovered Io, Europa, Ganymede, and Callisto.

1.55 Jupiter - Exploration

Jupiter, being the largest planet in the solar system and the nearest of the so-called gas giants, has long been intriguing to astronomers. In the early 1970s, we began sending spacecraft to study Jupiter. A chronological list of these probes, sorted by launch date, follows:

```
  Pioneer 10 - Mar.  3/72
  Pioneer 11 - Apr.  6/73
  Voyager 1  - Sep.  5/77
  Voyager 2  - Aug. 20/77
  Ulysses    - Oct.  6/90
  Galileo    - Oct. 18/89
```

1.56 Jupiter - Physical Features

Jupiter is the largest planet in the solar system. It is more than twice as massive as all the other objects in the solar system combined (excluding the Sun, of course).

Jupiter, like the rest of the gas giant planets (Saturn, Uranus, and Neptune) does not have a solid surface. Instead, the gaseous material they are made of just gets more and more dense with depth. What we see when we look at these planets is just the tops of the clouds high in their atmospheres (where the pressure is approximately equal to that of the Earth).

Most of our current knowledge about Jupiter comes from information returned by the highly successful Pioneer and Voyager spacecraft.

View Jupiter and nearby moons, as seen from Voyager

Structure of Jupiter

Starting at the outermost regions of Jupiter, we find that the planet is composed of approximately 90% hydrogen and 10% helium. This composition is thought to be quite similar to that of the primordial nebula from which the solar system originated. In these regions, the hydrogen and helium exist in gaseous form, as they would on Earth.

As we go deeper into the planet, we find that the atmospheric pressure increases continuously. Eventually, we reach a stage where the pressure becomes so intense that the hydrogen/helium combination begins to get compressed into a liquid state. Near the center of Jupiter, the pressure is believed to be 4 million times greater than that of the Earth's atmosphere at sea level. At this pressure, a rather exotic form of hydrogen exists - that of a liquid metal. This hydrogen conducts electricity, and it is assumed that currents within the vast pool give rise to Jupiter's intense magnetic field.

As we proceed still deeper into the planet, we find ourselves at the core. It is thought that this core is composed of rocky material 10 to 15 times more massive than the Earth.

Weather systems

Jupiter is the home to weather systems many orders of magnitude more violent than are found on Earth. High velocity winds, similar to our jet stream, move around the planet, confined to particular regions of latitude. However, the winds in adjacent bands blow in opposite directions. This causes regions of turbulence at their boundary. Perhaps the most famous example of this turbulence is the Great Red Spot.

The Great Red Spot is an immense storm, 12000 x 25000 km in size, constantly rotating in a counterclockwise direction, with the outer regions completing one rotation in four to six days. It is large enough to hold two Earths side by side. It appears to be a high pressure region whose cloud tops are significantly higher than the clouds surrounding it. However, it isn't the size of the Great Red Spot that stumps scientists. First detected over 300 years ago, nobody knows how this weather feature could have lasted so long.

View Great Red Spot

Similar storms have been observed at the turbulent boundary regions. But none of these features have matched the Great Red Spot in size, intensity, or duration.

Slight differences in the composition of the atmosphere in different bands result in different colors. Dark bands are called "belts", while brighter bands are called "zones". These features are easily visible from the Earth in a telescope and have been known for some time. But the complex vortices at the boundaries between two bands was not seen until the Voyager probes flew past the planet.

Magnetic field

Jupiter's magnetic field is much stronger than the Earth's. The influence of this field extends more than 650 million km from the planet - even past the orbit of Saturn! As a result, the region near Jupiter contains a high concentration of energetic particles originating from the Sun that become trapped in the field. They emit radiation that would be immediately lethal to an unprotected human being. As a result, even spacecraft have to be specially designed to withstand the effects.

Energy output

Jupiter has a rather hot interior, believed to be at a temperature of about 20,000 degrees C. Despite the fact that the planet is composed primarily of hydrogen and helium, it is not massive enough to produce this heat through nuclear fusion as a star does. Instead, the heat is believed to be caused by the slow gravitational compression of the planet. As a result, Jupiter actually radiates more heat energy into space than it receives from the Sun.

Jupiter emits energy at other wavelengths as well. Radio energy from the planet was first detected by Bernard Burke and Kenneth Franklin in 1955. They discovered that Jupiter emits continuous radio energy, as well as periodic energetic bursts. It is believed that these radio emissions originate from high energy particles trapped by the planet's strong magnetic field.

Jupiter's rapid rotation

Jupiter rotates about its axis faster than any other planet. The length of its day is slightly less than ten hours. This rapid rotation causes the planet to bulge out at the equator. As a result, the diameter of the planet is 9,276 km longer at the equator than at the poles.

Aurorae and lightning

When the Voyager probes passed Jupiter, they detected aurorae near the poles of the planet. These aurorae, similar to the Earth's northern and southern lights, are caused when material from Io travels along Jupiter's magnetic field to fall into the atmosphere near the polar regions. As it does so, it emits radiation which is observed as the aurorae.

In addition, the spacecraft detected huge bolts of lightning dancing between the cloud tops of the planet.

1.57 Jupiter's ring

It wasn't until the Voyager probes went past Jupiter that a ring around the planet was discovered. Even then, no scientists expected to find such an object, and it would have gone undetected for quite some time had not two astronomers taken the time to sift through the thousands of pictures returned from the encounter. The images of the ring were not obvious, with computer enhancement necessary for its detection.

Unlike the rings of Saturn, Jupiter's rings are extremely dark. They reflect only 5% of the light that hits them - this is why they had never been seen from the Earth. It is thought that they are composed of very small dust particles and rocky material. In fact, much as dust is most easily seen when it is floating in a shaft of light, the Voyager cameras saw the rings only when on the opposite side of them from the Sun. In this viewing geometry, the sunlight is scattered by the ring particles rather than reflected from them.

Two main structures to the ring were evident. Starting at a distance of 100,000 km from the center of Jupiter, a faint halo of particles could be seen. They extended for 22,800 km until reaching the main ring - a much denser structure 6,400 km wide. It is thought that the ring system is less than 10 km thick.

Because the ring particles are so small, they are affected greatly by atmospheric and magnetic drag. As a result, they cannot stay in orbit for long. If they have remained for a long time, they must be continuously resupplied. It is thought that Metis and Adrastea, two small satellites of Jupiter which orbit just outside the ring might supply the particles. Small meteoroids colliding with the surface of these moons would eject dust from the surface, and place it into orbit.

View Voyager picture of Jupiter’s ring

1.58 Jupiter - Observing the Planet

Because Jupiter’s orbit is outside that of the Earth, it does not go through a full cycle of phases as do the inner planets and the Earth’s moon. Though its phase does slightly change with time, its great distance from the Earth makes it appear to always be full, or almost full. Nevertheless, "The Digital Universe" simulates even these slight phases properly, and though the dark portion of Jupiter may not always be obvious when viewing the planet with the software, the percentage of the planet illuminated can always be obtained by clicking to obtain information on it.

In even small telescopes, the cloud bands of Jupiter can be seen (though moderate-sized telescopes are usually required to reveal the Great Red Spot). It should be kept in mind that since Jupiter does not have a solid surface like the Earth, features drift about with time. As a result, no software can generate the exact appearance of the planet for any given time. To do so would be equivalent to predicting the weather on Earth years in advance. Thus, the image obtained when zooming in on Jupiter should not be used as a reference as to what features are visible. It merely shows the state of the planet when observed by the Voyager probes, and is provided for interest only.

Since these features do change significantly, it is interesting to view Jupiter periodically and keep a record of how they change. Often cloud bands become lighter or darker, and sometimes new storms (smaller versions of the Red Spot) can be observed to form or dissipate.

The four largest moons of Jupiter can be easily seen with even small telescopes. "The Digital Universe" can help you identify these moons (as it can with many other moons in the solar system). Just zoom in to Jupiter enough so that the moons are visible. If you are using an inverting telescope, you may have to flip the X and Y dimensions to make the view match that in the telescope.

1.59 Jupiter - Collision with Comet Shoemaker-Levy 9

On March 23, 1993, Eugene and Carolyn Shoemaker, David Levy, and Philippe Bendjoya were at Palomar Observatory hunting for comets. Despite poor sky conditions and partially damaged film, they decided to take some photographs of the sky in the vicinity of Jupiter. Two days later, while examining the films, Carolyn Shoemaker discovered something that looked like a "squashed comet". They decided to ask Jim Scotti to confirm the object with the Spacewatch telescope on Kitt Peak in Arizona. Later that evening, he phoned back with the exciting news that there were at least 5 separate condensations in the comet. The discovery, denoted Comet Shoemaker-Levy 9, was immediately recognized as a rather unique object, though no one at the time realized how unique it would prove to be.

Everyone wondered what had caused the comet to break apart like that. Several theories were postulated. Perhaps it had been rotating so quickly that it fell apart. Or maybe it had passed near Jupiter in the past, breaking into fragments in the planet's gravitational field. It turned out that the latter theory was the correct one.

By the end of May, Brian Marsden at the Minor Planet Center in Cambridge, Massachusetts had calculated that the comet had passed within about 50,000 km of Jupiter's cloud tops on July 8, 1992. This distance was near enough for tidal forces created by the planet's gravity to pull the object apart. But perhaps more significantly, it appeared as though the comet was going to orbit around Jupiter and collide with it in July, 1994!

This realization excited astronomers worldwide. For a long time, they had theorized on the effects of such a catastrophic collision. Some scientists had felt that comet collisions with the Earth have caused many of the mass extinctions of the past. Now, for the first time, they would be able to directly witness such an event.

Unfortunately, calculations showed that the impacts would occur on the side of Jupiter not visible from the Earth. Thus, we would be unable to view the impacts directly, but would have to be content with studying the effect the collisions had on the atmosphere as it rotated into view a few minutes later. Though this was a serious disadvantage, the spacecraft Galileo and Voyager 2 were both in a position to be able to observe the impacts directly. Voyager 2 was located too far away to be able to take any pictures of the impact - instead, it was hoped that instruments on the spacecraft could monitor the light originating from Jupiter as a whole, so that the intensity of any fireballs could be estimated. On the other hand, Galileo was situated much closer to the planet (it is scheduled to rendezvous with Jupiter on December 7, 1995), and as such would be able to take pictures of the impacts.

Meanwhile Comet Shoemaker-Levy 9 was studied extensively by telescopes all around the world in an effort to determine how many pieces it had broken into. Orbits were calculated for each fragment to help determine when the exact moment of its impact would be. This information would be vital in planning the times for Galileo to take pictures of Jupiter. Since Galileo's main antenna is not working properly, all information sent by the craft is done so by a small backup antenna. This antenna only has the capability of transmitting 10 bits per second, requiring hours or days to send a single picture to Earth. Thus, it was extremely important to fine-tune the impact times so that a minimum of pictures from Galileo would be required.

By May, 1994 the Hubble Space Telescope had identified at least 20 fragments from the original comet, all strung out more or less in a straight line. To identify individual fragments, each piece was given a letter identifier. Thus, the first piece to impact with Jupiter would be known as "SL-9A", the second as "SL-9B", etc. These labels are provided in the following picture.

View Hubble picture of SL9, 2 months before impact

In the time preceding the impact, several fragments were observed to split into further pieces. The individual fragments were given further designations by appending a number after the letter. Thus, when fragment Q split into two pieces, they became known officially as "SL-9Q1" and "SL-9Q2".

Finally the big day arrived and fragments started hitting Jupiter. The date and time of impact for each fragment is given by the following table:

Fragment	Date and time of impact (GMT)
A	July 16/94 20:11
B	July 17/94 02:53
C	July 17/94 07:12
D	July 17/94 11:54
E	July 17/94 15:11
F	July 18/94 00:33
G	July 18/94 07:33:32
H	July 18/94 19:31:59
K	July 19/94 10:24:14
L	July 19/94 22:16:48
N	July 20/94 10:29:17
P2	July 20/94 15:23
Q2	July 20/94 19:44
Q1	July 20/94 20:13
R	July 21/94 05:34
S	July 21/94 15:15
T	July 21/94 18:10
U	July 21/94 21:55
V	July 22/94 04:23
W	July 22/94 08:06:12

As hoped, Galileo functioned properly and returned a series of spectacular images of the collision. One such sequence was the impact of the last fragment, "W". At this time, Galileo was approximately 238,000,000 km from Jupiter. Four images in visible light were taken, at intervals of 2.3 seconds.

In the first image, taken at 8:06:10 GMT, no impact can be observed. In the next three, a point of light appears, brightens dramatically, and then fades. In addition, dark spots from previous impacts can be seen to the right of the flash, on the day side of Jupiter. It is not yet known whether the flash observed by Galileo is due to the fragment burning as it entered the atmosphere of Jupiter, or whether it is a view of the subsequent explosion and fireball.

View SL-9W impact from Galileo

The view from Hubble didn’t disappoint astronomers either. Though unable to view the impacts directly, it did reveal a surprising amount of detail in the atmosphere as the impact site rotated into view. The largest piece, fragment ‘G’, entered the Jovian atmosphere at a 45 degree angle, and resulted in debris being thrown out asymmetrically. The thin ring surrounding the impact site is caused by the sonic boom after impact. As this picture was taken almost 2 hours after the actual impact occurred, this ring already measures about 7,500 km across - more than half the size of the Earth.

View SL-9G impact from Hubble

Images taken of the impact sites from infrared cameras on Earth have yielded a great deal of information concerning the energy of impact. Spectrae of the sites will help scientists to determine what may lay beneath the clouds of Jupiter, as it is thought that some of the underlying material may have been "splashed up" towards the surface.

It will take years for scientists to fully understand the wealth of information gathered from Galileo, Voyager 2, and observatories worldwide. So far, one of the biggest surprises has been related to the scars that the impacts have left in the atmosphere of the planet. Scientists never expected them to be so big, so dark, or last for so long. Several of these scars are two or three times larger than the Earth, and are only gradually fading. When the impacts occurred, they were easily visible through small amateur telescopes.

1.60 Jupiter - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience. For images of Jupiter’s moons, please follow the links to the satellite of interest, provided at the introductory screen for information on the planet.

```
Jupiter and its moons, taken from the Voyager probes
The Great Red Spot
Backlit image of Jupiter’s rings
Comet Shoemaker-Levy 9 two months before collision
Galileo image of fragment W impact
Hubble image of fragment G impact site
```

1.61 Ganymede - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Galileo
Date of Discovery......................1610
Alternate identification.........Jupiter III
Mass...............................1.48e23 kg  (0.02477 times that of Earth)
Radius..............................2631 km. (0.41250 times that of Earth)
Surface gravity.....................1.427 m/s^2 (0.145 times that of Earth)
Escape velocity.....................2.693 km/s
Apparent semidiameter at 1 AU...........3.65 arcseconds
Average density.......................1.94 g/cm^3
Magnitude at 1 AU.....................-2.09
Geometric Albedo.......................0.42

Atmosphere..............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........7.1545530 days
Orbital period.......................7.1545530 days
Average orbital velocity.................10.88 km/sec.
Eccentricity.............................0.002
```

```
Inclination of orbit to Jupiter's equator..0.21 degrees
Distance from center of Jupiter:
  Shortest.......................1,068,000 km
  Average........................1,070,000 km
  Greatest.......................1,072,000 km
```

1.62 Ganymede - Description

Ganymede (pronounced GAN-ee-meed) was discovered by Galileo in 1610. In Greek legend, Ganymede was a beautiful youth who was the son of the king of Troy. One day, Zeus saw Ganymede on Mount Ida, and was so impressed with his beauty that he carried him off to Mount Olympus to become a cupbearer to the gods.

Ganymede is the largest moon in the solar system, with a diameter of 5262 km. In fact, it is larger than the planets Mercury and Pluto, and if it were in orbit about the Sun instead of Jupiter it would be considered a planet instead of just a moon.

It is thought that Ganymede consists of a rocky core with a mantle of liquid water and a crust of rock and ice. It is heavily cratered, particularly in the darker regions. Unlike craters on the Moon, however, these craters are relatively flat. It is believed that the comparatively weak nature of Ganymede's crust of ice makes it impossible to support such large features for any length of time.

A significantly different terrain can be seen in the lighter areas. Massive ridges and troughs thousands of kilometers long seem to have been formed relatively recently through tectonic processes (similar to the process forming mountains on the Earth).

No atmosphere has been detected on Ganymede.

1.63 Callisto - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Galileo
Date of Discovery......................1610
Alternate identification..........Jupiter IV
Mass..............................1.08e23 kg  (0.01808 times that of Earth)
Radius.............................2400 km. (0.37629 times that of Earth)
Surface gravity...................1.251 m/s^2 (0.128 times that of Earth)
Escape velocity...................2.450 km/s
Apparent semidiameter at 1 AU...........3.33 arcseconds
Average density........................1.86 g/cm^3
Magnitude at 1 AU.....................-1.05
Geometric Albedo........................0.20

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
```

```
Sidereal Rotational period...........16.689018 days
Orbital period.......................16.689018 days
Average orbital velocity..................8.21 km/sec.
Eccentricity............................0.007
Inclination of orbit to Jupiter's equator..0.51 degrees
Distance from center of Jupiter:
  Shortest.......................1,870,000 km
  Average........................1,883,000 km
  Greatest.......................1,896,000 km
```

1.64 Callisto - Description

Callisto (pronounced kah-LISS-toe) was discovered by Galileo in 1610. In Greek mythology, Callisto was a nymph who was beloved by Zeus, but hated by his wife Hera. She changed her into a bear, and Zeus placed her in the sky as the constellation Ursa Major (the Big Bear).

Callisto is larger than the planet Pluto, and only slightly smaller than Mercury. It is so large that if it were in orbit about the Sun instead of Jupiter, it would be considered a planet instead of just a moon.

It is thought that Callisto consists of a rocky core surrounded by a mantle of liquid water and a crust of rock and ice. A great deal of craters are observed on the satellite, indicating that its surface is quite old. But like Ganymede, the craters on the surface of Callisto are relatively flat. It is thought that the rather weak crust of ice is unable to support large features for any length of time.

The largest feature on Callisto is a huge impact basin known as "Valhalla". This crater is about 300 km in diameter, with a series of ridges extending out to more than 1,500 km from the center.

Unlike Ganymede, there is no evidence of tectonic activity. No atmosphere has been detected on Callisto.

1.65 Io - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.........................Galileo
Date of Discovery......................1610
Alternate identification..........Jupiter I
Mass.................................8.94e22 kg  (0.01496 times that of Earth)
Radius..................................1815 km. (0.28457 times that of Earth)
Surface gravity.......................1.811 m/s^2 (0.185 times that of Earth)
Escape velocity.......................2.564 km/s
Apparent semidiameter at 1 AU...........2.52 arcseconds
Average density........................3.55 g/cm^3
Magnitude at 1 AU.....................-1.68
Geometric Albedo........................0.61

Atmosphere.....................Trace of sulfur dioxide
```

```
Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........1.7691378 days
Orbital period.......................1.7691378 days
Average orbital velocity.................17.35 km/sec.
Eccentricity.............................0.004
Inclination of orbit to Jupiter's equator..0.04 degrees
Distance from center of Jupiter:
  Shortest........................420,000 km
  Average.........................422,000 km
  Greatest........................424,000 km
```

1.66 Io - Description

Io (pronounced EYE-oh) was discovered by Galileo in 1610. In Greek mythology, Io was the daughter of Inachus. Zeus fell in love with her, and his wife Hera became jealous. So, Zeus changed Io into a heifer to hide her from Hera. Nevertheless, Hera found out and sent the monster Argus to guard Io from Zeus. Zeus sent Hermes to rescue Io. After the rescue succeeded, Hera then sent a gadfly to sting Io, who wandered all over the world to escape. Arriving in Egypt, Io was changed back into a woman and gave birth to a son, Epaphus, who was to be the ancestor of Hercules.

In real life, Io is as unique as its mythological namesake. While looking for a star in one of the images taken of Io, Linda Morabito at the Jet Propulsion Laboratory (JPL) discovered a strange, umbrella-shaped plume seeming to emerge on the edge of the satellite. It turned out that Voyager 1 had caught a volcano in the act of erupting. This was significant in that it was the first time an active volcano had been discovered on any object in the solar system other than the Earth.

Voyager 1 observed a total of 9 active volcanoes on Io altogether. Voyager 2 observed eight of the nine - the largest had finished its eruption by the time the spacecraft arrived. Plumes were often observed to rise more than 300 km above the planet's surface, with material being ejected at speeds over 1 km/sec. By comparison, the ejection velocities of Mount Etna, one of the most explosive volcanoes on the Earth, reached only 50 metres/sec. A combination of molten silicate rock, sulfur, sodium, and sulfur dioxide is believed to erupt from the volcanoes.

It appears as though the heat required to drive the volcanoes comes from tidal forces on Io. As Io revolves around Jupiter, the nearby satellites Europa and Ganymede perturb its orbit. This continual "tug-of-war" results in tidal bulging of the planet's surface by as much as 100 metres. By comparison, a typical tidal bulge on the Earth is rarely more than 1 metre. The friction associated with such movement produces vast quantities of heat. Though the average temperature on Io is approximately -150 degrees C, there are several hot spots reaching temperatures as high as over 600 degrees C.

It is thought that Io is similar in structure to the inner rocky planets (such as Earth), but lacks an iron core. There are very few craters on the sulfur-coated surface. It is presumed that the active volcanism quickly covers any craters which may form on the satellite.

Io cuts through the magnetic field lines of Jupiter in its orbit around the planet. In doing so, it creates a large electric current of 400,000 volts and 3 million amperes which flows between the satellite and the planet. It also strips away 1000 kg of material from Io each second in the form of energetic ions which glow with ultraviolet light. This material creates the so-called "Io plasma torus" of extremely intense radiation. Some of the more energetic sulfur and oxygen ions fall along Jupiter's magnetic field lines into the atmosphere of the planet, creating spectacular aurorae.

Unlike the other Galilean satellites (Europa, Ganymede, and Callisto), no water was detected on the surface of Io.

1.67 Europa - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Galileo
Date of Discovery......................1610
Alternate identification..........Jupiter II
Mass..............................4.80e22 kg  (0.00803 times that of Earth)
Radius.............................1569 km  (0.24600 times that of Earth)
Surface gravity.......................1.300 m/s^2 (0.133 times that of Earth)
Escape velocity.......................2.020 km/s
Apparent semidiameter at 1 AU...........2.18 arcseconds
Average density........................3.01 g/cm^3
Magnitude at 1 AU.....................-1.41
Geometric Albedo.......................0.64

Atmosphere..................trace of oxygen

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period............3.5511810 days
Orbital period.......................3.5511810 days
Average orbital velocity..................13.74 km/sec.
Eccentricity.............................0.009
Inclination of orbit to Jupiter's equator..0.47 degrees
Distance from center of Jupiter:
  Shortest.........................665,000 km
  Average..........................671,000 km
  Greatest.........................677,000 km
```

1.68 Europa - Description

Europa (pronounced yoo-ROH-puh) was discovered by Galileo in 1610. In Greek mythology, Europa was a Phoenician princess. Zeus fell in love with her, so he changed himself into a beautiful white bull and mingled with her father's herds of cattle. When Europa saw the bull, she was struck by its gentleness and climbed onto its back. Immediately, Zeus dashed off into the sea and swam to Crete with her on his back. Once there, she bore him three sons, and later became the wife of Asterius, king of Crete.

Perhaps the most striking feature of this satellite is that it is virtually flat. It may well be the flattest object in the solar system, with little vertical relief. Only three craters larger than 5 km in diameter have been found. It is thought to consist of a crust of water ice 5 km thick. Below that is a vast ocean of liquid water 50 km deep or more. Silicate rock is believed to make up the interior of the planet, with little or no iron core.

On the surface of Europa, many long markings can be seen in the ice. It is thought that these markings were caused by fractures developing in the ice that were filled in with liquid water from below.

The Voyager probes did not get a very good look at the surface of Europa, only mapping a small portion of it. It is hoped that the Galileo spacecraft will provide a great deal of additional data of the satellite when it arrives at the Jovian system in late 1995.

In the February 23, 1995 issue of the journal "Nature", a team of researchers led by Doyle Hall at the Johns Hopkins University and the Space Telescope Science Institute in Baltimore reported finding evidence of an extremely tenuous atmosphere of molecular oxygen surrounding Europa. The surface pressure is barely one hundred billionth that on the Earth.

Researches used the Goddard High Resolution Spectrograph (GHRS) instrument on the Hubble Space Telescope to perform the required measurements on June 2, 1994. Upon releasing their findings, the scientists warned that the existence of oxygen should not be misinterpreted as an indication of life on Europa. The surface is simply too cold (-145 degrees C) to support life as we know it. On the Earth, oxygen in the atmosphere is maintained in its relative proportion by biological processes. On Europa, dust and charged particles hit the icy surface to produce small quantities of water vapour. This water vapour then undergoes a series of chemical reactions resulting in the release of its constituent atoms - hydrogen and oxygen. Hydrogen, being lighter, escapes into space more quickly than the oxygen, producing a predominantly oxygen atmosphere. This oxygen must be continuously replenished, however.

1.69 Amalthea - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Barnard
Date of Discovery......................1892
Alternate identification...........Jupiter V
Mass...............................7.17e18 kg  (1.20e-6 times that of Earth)
Dimensions......................270x166x150 km  (0.02117 times that of Earth)
Surface gravity.......................0.007 m/s^2 (7e-4  times that of Earth)
Escape velocity.......................0.060 km/s
Apparent semidiameter at 1 AU..........0.19 arcseconds
Average density.........................1.8 g/cm^3
Magnitude at 1 AU.......................7.4
Geometric Albedo.......................0.05

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
```

```
Sidereal Rotational period............0.4981791 days
Orbital period........................0.4981791 days
Average orbital velocity..................26.48 km/sec.
Eccentricity..............................0.003
Inclination of orbit to Jupiter's equator..0.40 degrees
Distance from center of Jupiter:
  Shortest.........................180,000 km
  Average..........................181,000 km
  Greatest.........................182,000 km
```

1.70 Amalthea - Description

Amalthea (pronounced am-al-THEE-ah) was discovered by Barnard in 1892. In Roman mythology, Amalthea was a nymph who nursed Jupiter with goat's milk when he was young.

The satellite is quite small and irregular, having dimensions of 270x166x150 km in diameter. The surface exhibits many craters, some being extremely large in relation to the size of the satellite. The largest such crater is denoted "Pan", and measures 100 km across.

The surface of Amalthea is a reddish brown in color. It is thought that this color arises from a sulphur dust originating from Io. Its composition is thought to be similar to that of an asteroid.

Like most of Jupiter's satellites (and our own Moon), Amalthea rotates synchronously, keeping the same side permanently facing Jupiter. Its long axis remains forever pointed towards the planet.

Like Io, Amalthea gives off more heat (produced by tidal friction) than it receives from the Sun.

1.71 Himalia - Fast Facts

```
Physical Characteristics
------------------------
Discoverer........................C. Perrine
Date of Discovery......................1904
Alternate identification..........Jupiter VI
Mass...............................9.56e18 kg  (1.60e-6 times that of Earth)
Radius....................................93 km  (0.01458 times that of Earth)
Surface gravity.......................0.073 m/s^2 (8e-3  times that of Earth)
Escape velocity.......................0.117 km/s
Apparent semidiameter at 1 AU...........0.13 arcseconds
Average density.........................2.8 g/cm^3
Magnitude at 1 AU......................8.14
Geometric Albedo.......................0.03

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
```

```
Sidereal Rotational period.................0.4 days
Orbital period........................250.5662 days
Average orbital velocity..................3.34 km/sec.
Eccentricity............................0.15798
Inclination of orbit to Jupiter’s equator.27.63 degrees
Distance from center of Jupiter:
  Shortest.......................9,666,000 km
  Average.......................11,480,000 km
  Greatest......................13,294,000 km
```

1.72 Himalia - Description

Himalia (pronounced hih-MA-lee-uh) was discovered by C. Perrine in 1904. In Greek mythology, Himalia was a nymph who bore three sons of Zeus.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Elara, Leda, Himalia, and Lysithea may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces.

1.73 Thebe - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Stephen Synnott
Date of Discovery......................1979
Alternate identification.........Jupiter XIV, 1979J1
Mass..............................7.77e17 kg  (1.30e-7 times that of Earth)
Dimensions.........................110x90 km  (0.00862 times that of Earth)
Surface gravity....................0.0043 m/s^2 (4e-4  times that of Earth)
Escape velocity.......................0.030 km/s
Apparent semidiameter at 1 AU..........0.08 arcseconds
Average density.........................1.5 g/cm^3
Magnitude at 1 AU.......................9.0
Geometric Albedo........................0.05

Atmosphere..............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...............0.6745 days
Orbital period...........................0.6745 days
Average orbital velocity.................23.91 km/sec.
Eccentricity..............................0.015
Inclination of orbit to Jupiter’s equator...0.8 degrees
Distance from center of Jupiter:
  Shortest........................219,000 km
  Average.........................222,000 km
  Greatest........................225,000 km
```

1.74 Thebe - Description

Thebe (pronounced THEE-bee) was discovered by Stephen Synnott in 1979 by studying the images returned from Voyager 1. In Greek mythology, Thebe was a nymph and the daughter of the river god Asopus.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. Like many of the satellites in the solar system, Thebe exhibits synchronous rotation, keeping the same side always pointed towards Jupiter.

1.75 Elara - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.......................C. Perrine
Date of Discovery......................1905
Alternate identification.........Jupiter VII
Mass...............................7.77e17 kg  (1.30e-7 times that of Earth)
Radius...................................38 km  (0.00596 times that of Earth)
Surface gravity......................0.0359 m/s^2 (0.004 times that of Earth)
Escape velocity.......................0.037 km/s
Apparent semidiameter at 1 AU..........0.05 arcseconds
Average density.........................3.3 g/cm^3
Magnitude at 1 AU.....................10.07
Geometric Albedo.......................0.03

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period.................0.5 days
Orbital period........................259.6528 days
Average orbital velocity..................3.29 km/sec.
Eccentricity...........................0.20719
Inclination of orbit to Jupiter's equator.24.77 degrees
Distance from center of Jupiter:
  Shortest.......................9,305,000 km
  Average.......................11,737,000 km
  Greatest......................14,169,000 km
```

1.76 Elara - Description

Elara (pronounced EE-lar-uh) was discovered by C. Perrine in 1905. In Greek mythology, Elara was the mistress of Zeus and mother of Tityus the giant.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Elara, Leda, Himalia, and Lysithea may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces.

1.77 Pasiphae - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer.......................P. Melotte
 Date of Discovery......................1908
 Alternate identification........Jupiter VIII
 Mass...............................1.91e17 kg  (3.20e-8 times that of Earth)
 Radius...................................25 km  (0.00392 times that of Earth)
 Surface gravity......................0.0210 m/s^2 (0.002 times that of Earth)
 Escape velocity.......................0.032 km/s
 Apparent semidiameter at 1 AU..........0.03 arcseconds
 Average density.........................2.9 g/cm^3
 Magnitude at 1 AU.....................10.33
 Geometric Albedo.......................0.03

 Atmosphere.............................None

 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period.............unknown
 Orbital period...........................-735 days (*)
 Average orbital velocity..................2.32 km/sec.
 Eccentricity.............................0.378
 Inclination of orbit to Jupiter's equator...145 degrees
 Distance from center of Jupiter:
   Shortest.....................14,617,000 km
   Average......................23,500,000 km
   Greatest.....................32,383,000 km
* Pasiphae revolves in a retrograde direction.  To keep this clear, the orbital
period is specified as a negative number of days.
```

1.78 Pasiphae - Description

Pasiphae (pronounced pah-SIFF-ah-ee) was discovered by P. Melotte in 1908. In Greek mythology, Pasiphae was the wife of Minos (son of Zeus and Europa) and mother of the Minotaur.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Pasiphae, Ananke, Carme, and Sinope may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces.

1.79 Metis - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer..................Stephen Synnott
 Date of Discovery......................1979
 Alternate identification.........Jupiter XVI, 1979J3
 Mass...............................9.56e16 kg  (1.60e-8 times that of Earth)
 Radius...................................20 km  (0.00314 times that of Earth)
```

```
Surface gravity......................0.0159 m/s^2 (0.002 times that of Earth)
Escape velocity.......................0.025 km/s
Apparent semidiameter at 1 AU...........0.03 arcseconds
Average density.........................2.8 g/cm^3
Magnitude at 1 AU......................10.8
Geometric Albedo........................0.05

Atmosphere..............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.294780 days
Average orbital velocity..................31.55 km/sec.
Eccentricity............................0.000
Inclination of orbit to Jupiter's equator.....0 degrees
Distance from center of Jupiter.........127,960 km
```

1.80 Metis - Description

Metis (pronounced MEE-tis) was discovered by Stephen Synnott in 1979 by studying the images returned from Voyager 1. In Greek mythology, Metis was a consort of Zeus.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Metis and Adrastea may be the sources of the material which replenishes Jupiter's ring, since they orbit just outside it.

1.81 Carme - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.....................S. Nicholson
Date of Discovery......................1938
Alternate identification..........Jupiter XI
Mass..............................9.56e16 kg  (1.60e-8 times that of Earth)
Radius.................................20 km  (0.00314 times that of Earth)
Surface gravity......................0.0159 m/s^2 (0.002 times that of Earth)
Escape velocity.......................0.025 km/s
Apparent semidiameter at 1 AU...........0.03 arcseconds
Average density.........................2.8 g/cm^3
Magnitude at 1 AU.....................11.33
Geometric Albedo........................0.02

Atmosphere..............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period...........................-692 days (*)
Average orbital velocity..................2.37 km/sec.
```

```
 Eccentricity............................0.20678
 Inclination of orbit to Jupiter's equator...164 degrees
 Distance from center of Jupiter:
   Shortest.......................17,927,000 km
   Average........................22,600,000 km
   Greatest.......................27,273,000 km
* Carme revolves in a retrograde direction.  To keep this clear, the orbital
period is specified as a negative number of days.
```

1.82 Carme - Description

Carme (pronounced KAR-mee) was discovered by S. Nicholson in 1938. In Greek mythology, Carme and Zeus were the parents of Britomartis, a Cretan goddess.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Pasiphae, Ananke, Carme, and Sinope may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces.

1.83 Lysithea - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer.....................S. Nicholson
 Date of Discovery.....................1938
 Alternate identification...........Jupiter X
 Mass...............................7.77e16 kg  (1.30e-8 times that of Earth)
 Radius..................................18 km  (0.00282 times that of Earth)
 Surface gravity.......................0.016 m/s^2 (0.002 times that of Earth)
 Escape velocity.......................0.024 km/s
 Apparent semidiameter at 1 AU..........0.02 arcseconds
 Average density.........................3.1 g/cm^3
 Magnitude at 1 AU......................11.7
 Geometric Albedo.......................0.03

 Atmosphere............................None

 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..............unknown
 Orbital period..........................259.22 days
 Average orbital velocity..................3.29 km/sec.
 Eccentricity..............................0.107
 Inclination of orbit to Jupiter's equator.29.02 degrees
 Distance from center of Jupiter:
   Shortest.......................10,466,000 km
   Average........................11,720,000 km
   Greatest.......................12,974,000 km
```

1.84 Lysithea - Description

Lysithea (pronounced ly-SITH-ee-uh) was discovered by S. Nicholson in 1938. In Greek mythology, Lysithea was a daughter of Oceanus and one of Zeus' lovers.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Elara, Leda, Himalia, and Lysithea may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces.

1.85 Sinope - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer.....................S. Nicholson
 Date of Discovery......................1914
 Alternate identification..........Jupiter IX
 Mass..............................7.77e16 kg  (1.30e-8 times that of Earth)
 Radius...................................18 km  (0.00282 times that of Earth)
 Surface gravity......................0.0160 m/s^2 (0.002 times that of Earth)
 Escape velocity.......................0.024 km/s
 Apparent semidiameter at 1 AU..........0.02 arcseconds
 Average density.........................3.1 g/cm^3
 Magnitude at 1 AU......................11.6
 Geometric Albedo.......................0.03

 Atmosphere.............................None

 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..............unknown
 Orbital period...........................-758 days (*)
 Average orbital velocity..................2.27 km/sec.
 Eccentricity..............................0.275
 Inclination of orbit to Jupiter's equator...153 degrees
 Distance from center of Jupiter:
   Shortest......................17,183,000 km
   Average.......................23,700,000 km
   Greatest......................30,218,000 km
* Sinope revolves in a retrograde direction.  To keep this clear, the orbital
period is specified as a negative number of days.
```

1.86 Sinope - Description

Sinope (pronounced sih-NOH-pee) was discovered by S. Nicholson in 1914. In Greek mythology, Sinope was a woman unsuccessfully courted by Zeus.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Pasiphae, Ananke, Carme, and Sinope may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces. Sinope is one of the smallest moons in the solar system.

1.87 Ananke - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer.....................S. Nicholson
 Date of Discovery......................1951
 Alternate identification.........Jupiter XII
 Mass...............................3.82e16 kg  (6.39e-9 times that of Earth)
 Radius..................................15 km  (0.00235 times that of Earth)
 Surface gravity......................0.0113 m/s^2 (0.001 times that of Earth)
 Escape velocity.......................0.018 km/s
 Apparent semidiameter at 1 AU..........0.02 arcseconds
 Average density.........................2.7 g/cm^3
 Magnitude at 1 AU......................12.2
 Geometric Albedo.......................0.02

 Atmosphere............................None

 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..............unknown
 Orbital period...........................-631 days (*)
 Average orbital velocity..................2.44 km/sec.
 Eccentricity...........................0.16870
 Inclination of orbit to Jupiter's equator...147 degrees
 Distance from center of Jupiter:
   Shortest......................17,624,000 km
   Average.......................21,200,000 km
   Greatest......................24,776,000 km
* Ananke revolves in a retrograde direction.  To keep this clear, the orbital
period is specified as a negative number of days.
```

1.88 Ananke - Description

Ananke (pronounced a-NANG-kee) was discovered by S. Nicholson in 1951. In Greek mythology, Ananke and Zeus were the parents of Adrastea.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Pasiphae, Ananke, Carme, and Sinope may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces. Ananke is one of the smallest moons in the solar system.

1.89 Adrastea - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer.....................David Jewitt
 Date of Discovery......................1979
 Alternate identification..........Jupiter XV, 1979J2
 Mass...............................1.91e16 kg  (3.20e-9 times that of Earth)
 Dimensions.........................25x20x15 km  (0.00196 times that of Earth)
```

```
Surface gravity......................0.0032 m/s^2 (3e-4  times that of Earth)
Escape velocity.......................0.011 km/s
Apparent semidiameter at 1 AU...........0.02 arcseconds
Average density.........................4.5 g/cm^3
Magnitude at 1 AU......................12.4
Geometric Albedo.......................0.05

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period.............unknown
Orbital period.........................0.29826 days
Average orbital velocity.................31.48 km/sec.
Eccentricity.............................0.000
Inclination of orbit to Jupiter's equator.....0 degrees
Distance from center of Jupiter.........128,980 km
```

1.90 Adrastea - Description

Adrastea (pronounced a-DRAS-tee-uh) was discovered in 1979 by David Jewitt, a graduate student working under E. Danielson, by examining the images returned from Voyager 1. In Greek mythology, Adrastea was the daughter of Zeus and Ananke. She was known as the distributor of rewards and punishments.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Metis and Adrastea may be the sources of the material which replenishes Jupiter's ring, since they orbit just outside it.

In the photograph provided with "The Digital Universe", Adrastea appears circled in the left hand image. The exposure was 15 seconds, and the satellite was 1,400,000 km from Voyager. In order to confirm a moon's existence, two images are required. The right hand image is this confirmation, had an exposure time of 96 seconds. Due to the long exposure time, Adrastea (with an arrow pointing to it) appears as a short streak. Note that the direction of this streak is slightly different from that of a star in the upper left corner - evidence that the satellite was in motion.

The faint hazy band extending from upper right to lower left in both images is Jupiter's ring.

1.91 Leda - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.........................C. Kowal
Date of Discovery......................1974
Alternate identification........Jupiter XIII
Mass................................5.68e15 kg  (9.5e-10 times that of Earth)
Radius....................................8 km  (0.00125 times that of Earth)
Surface gravity......................0.006 m/s^2 (6e-4  times that of Earth)
```

```
Escape velocity.......................0.010 km/s
Apparent semidiameter at 1 AU...........0.01 arcseconds
Average density........................2.7 g/cm^3
Magnitude at 1 AU......................13.5
Geometric Albedo.......................0.02

Atmosphere.............................None

Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period.........................238.72 days
Average orbital velocity..................3.38 km/sec.
Eccentricity...........................0.14762
Inclination of orbit to Jupiter's equator.26.07 degrees
Distance from center of Jupiter:
  Shortest......................9,456,000 km
  Average......................11,094,000 km
  Greatest.....................12,732,000 km
```

1.92 Leda - Description

Leda (pronounced LEE-da) was discovered by C. Kowal in 1974. In Greek mythology, Leda was the queen of Sparta. She and Zeus were the parents of Helen and Pollux.

Since the paths of the Voyager probes did not take them near the satellite, very little is known about it. It is thought that Elara, Leda, Himalia, and Lysithea may be the remnants of a single asteroid that was captured by Jupiter and broken up by strong tidal forces. Leda is one of the smallest moons in the solar system.

1.93 Saturn - Fast Facts

```
Physical Characteristics
------------------------
Mass.............................5.6850e26 kg  (94.657 times that of Earth)
Equatorial radius.....................60268 km  (9.4491 times that of Earth)
Polar radius..........................54364 km  (8.5522 times that of Earth)
Surface gravity.......................10.44 m/s^2 (1.06 times that of Earth)
Escape velocity........................35.5 km/s
Apparent semidiameter at 1 AU..........83.72 arcseconds
Average density........................0.69 g/cm^3
Average temperature at 1 atmosphere.....-185 degrees C
Magnitude at 1 AU.....................-8.88
Geometric Albedo.......................0.47

Composition (by number of atoms):
    Hydrogen............................97%
    Helium...............................3%
    Methane, ammonia, 'rock'...........0.05%
```

```
 Number of known satellites................32 (20 confirmed)

                Titan      Hyperion    Pandora
                Rhea       Mimas       Atlas
                Iapetus    Phoebe      Helene
                Dione      Janus       Telesto
                Tethys     Epimetheus  Calypso
                Enceladus  Prometheus  Pan
     1995 S3    1995 S4

    Unconfirmed
    -----------
    1980 S35    1980 S36    1980 S12
    1981 S7     1980 S9   1980 S10
    1995 S1         1995 S2         (unnamed)
    1995 S5         1995 S6         1995 S7


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period, System I...10.233 hours
                             System III.10.656 hours
 Inclination of equator to orbit.........26.73 degrees
 Orbital period (length of year)........29.424 years
 Average orbital velocity...............9.6724 km/sec.
 Eccentricity.....................0.0555086217172
 Inclination of orbit to ecliptic.....2.488878 degrees
 Distance from Sun:
   Shortest.....................1,350,050,000 km ( 9.02453 AU)
   Average......................1,429,394,000 km ( 9.55491 AU)
   Greatest.....................1,508,738,000 km (10.08529 AU)
```

1.94 Saturn - Mythology

Saturn was named after the Roman god of fertility and planting. He was similar to the Greek god Cronus, who was the son of Uranus and the father of Zeus. Saturn’s wife was Ops, the goddess of fertility and the harvest.

Each year, the Romans honored Saturn with a festival known as the "Saturnalia". The celebrations began on December 17th, and lasted seven days. During the festival, criminals could not be punished, schools and businesses were closed, Roman armies could not start wars, and slaves and masters became equals.

Several people believe that the Christmas traditions of feasting and giving gifts might have had the origins with the Saturnalia.

1.95 Saturn - Discovery

Saturn is a bright object in the evening sky, and has thus been known since prehistoric times. Of course, the ancients did not realize that Saturn was a planet much larger than the Earth, but its motion across the background sky set it apart from the stars.

In 1610, Galileo used his telescope to discover some "projections" jutting past the disk of the planet. He did not know what they were, and thought that they might be large satellites. In 1655, Christian Huygens, using a more powerful telescope, realized that these projections were actually a ring surrounding the planet. He thought that the ring was a solid sheet of some material. Then, in 1675, Jean Dominique Cassini discovered a gap in the ring and announced his correct hypothesis that the rings were actually made of a large number of tiny satellites.

1.96 Saturn - Exploration

In the early 1970s, we began sending spacecraft to study the outer planets. Though nothing has been sent with the sole purpose of visiting Saturn, three spacecraft have observed the planet while on a tour of the outer solar system. A chronological list of these probes, sorted by launch date, follows:

```
  Pioneer 11 - Apr.  6/73
  Voyager 1  - Sep.  5/77
  Voyager 2  - Aug. 20/77
```

In addition, the following spacecraft is planned for the near future:

```
  Cassini    - Oct.  6/97
```

1.97 Saturn - Physical Features

Saturn is the second largest planet in the solar system. Only Jupiter is larger.

Saturn, like the rest of the gas giant planets (Jupiter, Uranus, and Neptune) does not have a solid surface. Instead, the gaseous material they are made of simply gets more and more dense with depth. What we see when we look at these planets is simply the tops of the clouds high in their atmospheres (where the pressure is approximately equal to that of the Earth).

Most of our current knowledge about Saturn comes from information returned by the highly successful Pioneer and Voyager spacecraft.

View Saturn and nearby moons, as seen from Voyager

Structure of Saturn

Starting at the outermost regions of Saturn, we find that the planet is composed of approximately 97% hydrogen and 3% helium. This composition is thought to be quite close to that of the primordial nebula from which the solar system originated. In these regions, the hydrogen and helium exist in gaseous form, as they would on Earth.

As we go deeper into the planet, we find that the atmospheric pressure increases continuously. Eventually, we reach a stage where the pressure becomes so intense that the hydrogen/helium combination begins to get compressed into a liquid state. Near the center of Saturn, the pressure is extremely high. Despite the fact that the temperature is 12,000 degrees C, a rather exotic form of hydrogen exists - that of a liquid metal. This hydrogen conducts electricity, and it is assumed that currents within the vast pool give rise to Saturn’s strong magnetic field. The magnetic field, though weaker than Jupiter’s, extends out to one or two million kilometers from the planet. The magnetic axis is almost perfectly aligned with Saturn’s axis of rotation, tipped less than a degree away.

As we proceed still deeper into the planet, we find ourselves at the core. It is thought that this core is formed of rocky material similar in composition and size to the Earth.

This planet of primarily gas and liquid is surprisingly light. With a density of only 0.69 grams per cubic centimeter, Saturn would float if we had an ocean big enough to put it in.

Weather systems

Despite the fact that Saturn is similar in composition to Jupiter, cloud features and the bands so prominent on Jupiter are much fainter. This is because that Saturn is colder than Jupiter and the chemicals creating the shades of color occur lower in the atmosphere of the planet. Like Jupiter’s "Great Red Spot", huge storms sometimes occur. In 1990 and again in 1994, the Hubble Space Telescope observed enormous white clouds near Saturn’s equator. But unlike the Great Red Spot, these features are more short lived - no evidence was present of these weather systems during the Pioneer and Voyager encounters.

The wind blows at extremely high speeds on Saturn. At the equator, the velocity can exceed 1,800 km/hour. Winds near the equator blow in an easterly direction, but at latitudes greater than 35 degrees, winds alternate east and west as latitude increases.

Energy output

Saturn has a rather hot interior, believed to be at a temperature of about 12,000 degrees C. Despite the fact that the planet is composed primarily of hydrogen and helium, it is not massive enough to produce this heat through nuclear fusion as a star does. Instead, the heat is believed to be caused by the slow gravitational compression of the planet.

As a result, Saturn actually radiates more heat energy into space than it receives from the Sun.

Saturn’s rapid rotation

Saturn rotates about its axis quite quickly. Despite the fact that it is much larger than the Earth, the length of its day is just a bit more than ten hours. This rapid rotation causes the planet to bulge out at the equator and flatten at the poles. In fact, the diameter of Saturn is 10% less when measured through the poles as compared to a measurement along the equator. The discrepancy is 11,808 km and is quite apparent when observing the planet through a telescope. The disk looks a bit "squashed". "The Digital Universe" takes into account this flattening when drawing the appearance of Saturn (and any other solar system object, for that matter).

1.98 Saturn's rings

First detected by Galileo in 1610, the ring of Saturn wasn't identified as such until 1655 by Christian Huygens. At that time, it was thought that the ring was composed of some sheet of solid material encircling the planet. Then in 1675, Jean Cassini used a larger telescope and correctly hypothesized that the rings were actually made up of a large number of tiny satellites. He also observed a gap in the ring, which became known as the "Cassini division".

Over time, fainter rings and narrower gaps were discovered. The rings were given letters for identification, while the gaps inherited the name of the discoverer. The principal components of Saturn's ring system can be summarized by the following table:

Name	Distance (km)	Width (km)
D	67,000	7,500
C	74,500	17,500
Maxwell Gap	87,500	270
B	92,000	25,500
Cassini Division	117,500	4,700
A	122,200	14,600
Encke Gap	133,570	325
Keeler Gap	136,530	35
F	165,800	30-500
G	166,000	8,000
E	180,000	300,000

NOTE: Distances are measured from the center of the planet.

Unlike the rings encircling other planets in our solar system, Saturn's rings are exceptionally bright and are an obvious feature when viewing the planet through the telescope. Since the A, B, and C rings are the easiest to see, "The Digital Universe" draws these rings when generating the current appearance of Saturn. The C ring is substantially fainter than the other two, but is relatively easy to glimpse when viewed against the bright disk of Saturn.

The composition of the rings is similar to that of the other ring systems in our solar system. It is thought that most of the particles range in size from a few centimetres to several metres. A few objects a kilometer in size or more are expected, though they would be quite rare. The composition is thought to include water ice and rocky particles.

Despite the impressive appearance of Saturn's rings from Earth, there is really very little matter in them. The typical thickness of the ring system is no more than 100 metres thick. If all the material in the rings were compressed into a single object, it would only be 100 km in diameter.

Because Saturn's north pole points in a different direction than the north pole of our Earth, the angle at which we view the rings varies throughout Saturn's orbit around the Sun. At some times, we view the impressive sight of the rings from slightly above or below. At other times, we see the rings nearly edge on.

Since the rings are so thin, they then appear invisible.

When the Voyager probes and Pioneer probes went to explore Saturn, they detected a number of interesting and unexpected things. Most obvious was the fact that the rings visible from the Earth were actually composed of thousands of smaller ‘ringlets’. Then, under computer enhancement, there appeared to be radial features, or "spokes" in the ‘B’ ring. According to well understood laws of celestial motion, particles in the ring nearer to Saturn must orbit more quickly than particles further from the planet. If the patterns were simply darker particles in the rings held in place by gravitational forces, the features could not be expected to last for long, as the different velocities at different parts of the spokes would cause them to break apart. But the Voyager probes observed these spokes remaining more or less the same in appearance for many revolutions around the planet. As a result, some scientists speculate that they are clouds of fine, dust-like particles levitated above the ring by electrostatic forces. But the exact mechanisms forming these features remains unknown.

View ‘spokes’ in the ring of Saturn

Though mostly circular, there are some irregularities in the shapes of the rings as well. Saturn’s F-ring was observed to be a complex structure made of of two narrow, intertwining rings. Various small "knots" in the structure may be clumps in the material comprising the rings, or small moons.

View portion of Saturn’s F-ring

A strong relationship between Saturn’s rings and moons was observed to exist. "Shepherding" moons tend to keep rings together, not allowing particles to stray too far from the central condensation. For example, Atlas, orbiting just outside the ‘A’ ring, seems to keep particles from straying outside the outer limits of the ring. Similarly, Prometheus and Pandora constrain the F-ring on both sides.

View shepherding satellites Prometheus and Pandora

Pan orbits inside the Encke Gap, apparently keeping it largely free of ring material.

View image of Pan, within the Encke Gap

The whole system of gravitational interactions between the satellites and moons of Saturn is still poorly understood.

Despite intensive study, the origin of the rings of Saturn and other planets remains unknown. There are several plausible hypotheses to explain their existence:

1. They formed at the same time as the planets
2. They are the result of a catastrophic collision between two former satellites of the planet.
3. A former satellite came too close to the planet and was ripped apart by tidal forces.

Recent evidence seems to suggest that the rings may have been around for less than 100,000,000 years (in which case, the rings could not have been formed at the same time as the planets). Since Saturn’s moons exert forces on particles in the ring system, they are stealing orbital energy from them. As these particles lose their energy, they slowly spiral nearer to the planet. According to the current understanding of the relationship between Saturn's rings and its moons, astronomers have calculated that within 100,000,000 years the ring structure would completely collapse.

1.99 Saturn - Observing the Planet

The most obvious feature of Saturn when observing the planet through a small telescope is its rings. The main rings are about as bright as the planet itself, and definitely make Saturn appear unique. Through larger telescopes, the Cassini division may be resolved.

The orientation of the ring plane varies during Saturn's revolution around the Sun. Because of this variation, we sometimes see the rings from slightly above, below, or edge-on. When we are at our maximum angular distance above or below the rings, they appear the most spectacular. Since the rings are so thin (only 100 metres thick, on average), they cannot be seen at all when we view them edge-on.

Because Saturn's orbit is outside that of the Earth, it does not go through a full cycle of phases as do the inner planets and the Earth's moon. Though its phase does slightly change with time, its great distance from the Earth makes it appear to always be full, or almost full. Nevertheless, "The Digital Universe" simulates even these slight phases properly, and though the dark portion of Saturn may not always be obvious when viewing the planet with the software, the percentage of the planet illuminated can always be obtained by clicking to obtain information on it.

Saturn's disk shows less detail in its cloud bands than Jupiter does, so an observation of the planet itself may prove unrewarding.

Saturn's largest moon, Titan, never appears brighter than about 8th magnitude. Nevertheless, it can still be seen as a small, starlike point with even a small telescope. It is best to wait until the satellite is at its maximum apparent distance from the planet so that it isn't obscured in the glare from Saturn. You can use "The Digital Universe" to help determine such a time.

Larger telescopes (6 inches and greater) are capable of observing some of the other satellites of Saturn (such as Rhea, Tethys and Dione).

1.100 Saturn - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience. For images of Saturn's moons, please follow the links to the satellite of interest, provided at the introductory screen for information on the planet.

Saturn and its moons, taken from the Voyager probes
Ring spokes
The 'braided' F-ring
F-ring shepherd moons

1.101 Titan - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Huygens
Date of Discovery......................1655
Alternate identification...........Saturn VI
Mass................................1.35e23 kg  (0.02260 times that of Earth)
Radius..............................2575 km  (0.40372 times that of Earth)
Surface gravity.....................1.358 m/s^2 (0.138 times that of Earth)
Escape velocity.....................1.870 km/s
Apparent semidiameter at 1 AU..........3.57 arcseconds
Average density.....................1.88 g/cm^3
Magnitude at 1 AU.....................-1.28
Geometric Albedo.......................0.21

Atmospheric composition (by number of atoms):
    Nitrogen............................80%
    Argon...............................15%
    Methane..............................5%
    Ethane, Carbon dioxide, Hydrogen
       cyanide........................trace
Atmospheric pressure at surface..........1.5 times that on Earth


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........15.9454207 days
Orbital period......................15.9454207 days
Average orbital velocity..................5.58 km/sec.
Eccentricity.........................0.029192
Inclination of orbit to Saturn's equator...0.33 degrees
Distance from center of Saturn:
  Shortest.......................1,186,160 km
  Average........................1,221,830 km
  Greatest.......................1,257,500 km
```

1.102 Titan - Description

Titan (pronounced TY-tun) was discovered by Huygens in 1655. In Greek mythology, the Titans were a family of giants. They were the children of Uranus and Gaea, who sought to rule the heavens but were overthrown by the family of Zeus.

For a long time, scientists thought that Titan was the largest satellite in the solar system. However, when Voyager 1 flew by the satellite, it revealed that Titan's atmosphere, originally discovered from ground observations by Kuiper was in fact much thicker than previously thought. Since scientists had unknowingly been viewing the atmosphere instead of the surface, the satellite itself was smaller than originally thought. The difference was enough to make Ganymede just slightly larger, and Titan was demoted to the second largest satellite.

Titan's atmosphere is unique among the various moons in the solar system.

Though several satellites contain a trace of atmosphere, none even come close to the density observed at Titan. At the surface of the moon, the atmospheric pressure is even 50% greater than that of the Earth at sea level. In addition to nitrogen, argon, and methane, several organic compounds have been found (ethane, hydrogen cyanide, and carbon dioxide). These compounds are formed when methane is destroyed by the Sun's radiation. The result is a thick orange smog that totally obscures the surface. It is believed that the current atmospheric conditions on Titan are similar to those experienced by the Earth when life was starting, since these hydrocarbon compounds are the building blocks for amino acids.

Curiously, Titan's atmosphere produces an "antigreenhouse effect", preventing some energy from reaching the surface. Christopher P. McKay of the NASA-Ames Research Center reported in the September 6, 1991 issue of "Science" that this effect could lower the temperature of Titan's surface by as much as 9 degrees C. However, methane and hydrogen gas in the lower atmosphere act as conventional greenhouse gases and overcompensate for the cooling, raising the temperature by 21 degrees C. Thus, the net effect is a temperature 12 degrees warmer than that which would be expected if Titan did not have an atmosphere.

Because of this smog, the Voyager cameras were unable to penetrate to the surface. When the Cassini spacecraft arrives at Titan in late 2004, it will generate a radar map of the surface, much as Magellan did at Venus. In addition, the "Huygens" probe on the Cassini spacecraft will descend through the atmosphere of Titan, returning data and images in its journey to the surface.

Despite the fact that the Voyager probes could not directly view the surface of the satellite, it did show a slight variation in color between the northern and southern hemispheres. The reason for this variation is unknown.

Scientists believe that Titan consists of a rocky core 3400 km in diameter, surrounded by various layers of water ice. Its interior may still be hot as a remnant of the gravitational compression which formed the satellite billions of years ago. At the surface of the moon, the temperature is about -180 degrees C. There are believed to be two layers of ethane clouds at about 200 km and 300 km above the surface. It is likely that these clouds would produce a rain of liquid ethane down to the surface, perhaps forming an ocean or lakes of ethane. Radar studies in June 1989 established that there is probably dry land in addition to such an ocean.

At periods during its orbit, Titan is located outside of Saturn's magnetosphere. Since the Voyager probes did not detect any magnetic field around Titan, it is exposed directly to the solar wind at these times. When this occurs, it is thought that some molecules from the top of Titan's atmosphere ionize and are carried away.

Through analyzing the light emitted by the star 28 Sagittarii occulted by Titan on July 3, 1989, astronomers were able to observe an interesting characteristic of the satellite's atmosphere. It appears as though its atmosphere is oblate (flattened at the poles) by about 1.7%. It is believed that this oblateness may be caused by the atmosphere circling the globe in 26 hours as compared to the 16 day rotation period for Titan itself.

The Voyager probes did not carry instruments capable of observations in the infrared. However, the atmosphere of Titan is more transparent to infrared light. Astronomers have used this fact to their advantage in making observations of the surface of Titan with the Hubble Space Telescope. Studies led by Peter H. Smith of the University of Arizona Lunar and Planetary Laboratory have revealed the existence of at least one bright region, or "continent" about the same size as Australia. The landing site for the "Huygens" probe of the Cassini spacecraft has been chosen just "offshore" of this feature.

1.103 Mimas - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.........................Herschel
Date of Discovery......................1789
Alternate identification...........Saturn I
Mass...............................3.80e19 kg  (6.36e-6 times that of Earth)
Radius..................................196 km  (0.03073 times that of Earth)
Surface gravity......................0.066 m/s^2 (7e-3  times that of Earth)
Escape velocity......................0.161 km/s
Apparent semidiameter at 1 AU..........0.27 arcseconds
Average density........................1.17 g/cm^3
Magnitude at 1 AU.......................3.3
Geometric Albedo........................0.5

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........0.94242181 days
Orbital period.......................0.94242181 days
Average orbital velocity.................14.33 km/sec.
Eccentricity............................0.0202
Inclination of orbit to Saturn’s equator...1.53 degrees
Distance from center of Saturn:
  Shortest.........................181,770 km
  Average..........................185,520 km
  Greatest.........................189,270 km
```

1.104 Mimas - Description

Mimas (pronounced MY-mas) was discovered by Herschel in 1789. In Greek mythology, Mimas was a Titan slain by Hercules.

It is felt that Mimas’ low density suggests that it is composed primarily of water ice. At the average temperature of -200 degrees C, this ice would become as hard as granite.

Mimas is heavily cratered, though the cratering is not uniform. Most of the surface is covered with craters greater than 40 km in diameter, except for the south polar region. There, the largest craters are typically 20 km in diameter. This suggests that some process has removed evidence of larger craters.

One of the craters, named Herschel after the moon's discoverer, is extremely large in comparison to the rest of the moon. 130 km wide and 10 km deep, this crater has a central peak 6 km high (almost as high as Mount Everest). On a moon with a diameter of only 400 km, the feature dominates the surface. Fracture marks on the side of the moon opposite the crater suggest that the force of collision almost destroyed Mimas.

1.105 Enceladus - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.........................Herschel
Date of Discovery......................1789
Alternate identification...........Saturn II
Mass.................................8.40e19 kg  (1.41e-5 times that of Earth)
Radius...................................250 km  (0.03920 times that of Earth)
Surface gravity........................0.090 m/s^2 (9e-3  times that of Earth)
Escape velocity........................0.211 km/s
Apparent semidiameter at 1 AU...........0.38 arcseconds
Average density.........................1.24 g/cm^3
Magnitude at 1 AU........................2.1
Geometric Albedo........................0.99

Atmosphere..............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........1.37021786 days
Orbital period.......................1.37021786 days
Average orbital velocity.................12.64 km/sec.
Eccentricity...........................0.00452
Inclination of orbit to Saturn's equator...0.00 degrees
Distance from center of Saturn:
  Shortest.........................236,900 km
  Average..........................238,020 km
  Greatest.........................239,100 km
```

1.106 Enceladus - Description

Enceladus (pronounced en-SELL-a-dus) was discovered by Herschel in 1789. In Greek mythology, Enceladus was a Titan defeated in battle and buried under Mount Etna by Athena.

Enceladus is the most reflective object in the solar system. This is because its surface is dominated by clean ice.

Many different types of terrain have been observed on Enceladus. The landscape varies from cratered regions, to smooth plains, to long cracks and ridges. Much of the surface appears relatively young, suggesting that Enceladus may still be geologically active. It may have a liquid interior, though if it were left alone it would have frozen long ago. Therefore, scientists have speculated that the satellite's interior may be heated by tidal effects with the nearby moons Tethys and Dione.

Enceladus may provide material for Saturn's "E" ring.

1.107 Tethys - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Cassini
Date of Discovery......................1684
Alternate identification..........Saturn III
Mass..............................7.55e20 kg  (1.26e-4 times that of Earth)
Radius...............................530 km  (0.08310 times that of Earth)
Surface gravity......................0.179 m/s^2 (0.018 times that of Earth)
Escape velocity......................0.436 km/s
Apparent semidiameter at 1 AU..........0.74 arcseconds
Average density.......................1.21 g/cm^3
Magnitude at 1 AU......................0.6
Geometric Albedo.......................0.9

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........1.88780216 days
Orbital period.......................1.88780216 days
Average orbital velocity.................11.35 km/sec.
Eccentricity..............................0.00
Inclination of orbit to Saturn's equator...1.86 degrees
Distance from center of Saturn:
  Shortest.........................294,660 km
  Average..........................294,660 km
  Greatest.........................294,660 km
```

1.108 Tethys - Description

Tethys (pronounced TEE-thiss) was discovered by Cassini in 1684. In Greek mythology, Tethys was a Titaness and sea goddess. She was the sister and wife of Oceanus.

Like many of the Saturnian satellites, the low density of Tethys suggests that it may be primarily composed of water ice. A large impact crater, called Odysseus, dominates the western hemisphere. 400 km in diameter, this crater provides evidence to suggest that the satellite may have been liquid in the past (if it were solid, chances are high that the moon would have shattered). Now, Odysseus is quite flat.

Another major surface feature evident on images of Tethys is "Ithaca Chasma", a huge valley 100 km wide and 3 to 5 km deep, running 3/4 of the way around the satellite. It is thought that as Tethys froze from its original liquid state, it expanded and cracked, creating features such as this valley.

Telesto and Calypso orbit at positions 60 degrees ahead and behind of Tethys, in the same orbit. There is no danger of collision however, since these points (known as Lagrange points) exist as stable locations in any orbit. The moons will never get substantially closer or further away from each other.

1.109 Dione - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Cassini
Date of Discovery......................1684
Alternate identification...........Saturn IV
Mass................................1.05e21 kg  (1.76e-4 times that of Earth)
Radius...................................560 km  (0.08780 times that of Earth)
Surface gravity........................0.223 m/s^2 (0.023 times that of Earth)
Escape velocity........................0.500 km/s
Apparent semidiameter at 1 AU...........0.78 arcseconds
Average density.........................1.43 g/cm^3
Magnitude at 1 AU.......................0.8
Geometric Albedo.........................0.7

Atmosphere..............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........2.73691474 days
Orbital period.......................2.73691474 days
Average orbital velocity.................10.03 km/sec.
Eccentricity..........................0.002230
Inclination of orbit to Saturn's equator...0.02 degrees
Distance from center of Saturn:
  Shortest.........................376,240 km
  Average..........................377,400 km
  Greatest.........................378,240 km
```

1.110 Dione - Description

Dione (pronounced die-OH-nee) was discovered by Cassini in 1684. In Greek mythology, Dione was the mother of Aphrodite and the wife of Zeus.

Dione is composed primarily of water ice, however since its density is somewhat higher than most of the other Saturnian satellites, it must have an appreciable amount of silicate rock as well.

Since Dione orbits Saturn in a "synchronous" orbit (always keeping the same side facing the planet), it is said to have a "leading" and "trailing" hemisphere. The leading hemisphere of Dione is heavily cratered and uniformly bright, whereas the trailing hemisphere contains a network of bright streaks on a dark background. On this hemisphere, there are few craters. In these respects, Dione is quite similar to Rhea, only smaller.

It is believed that shortly after its formation, Dione was a geologically active moon. During this period, ice volcanoes covered the whole surface, leaving a pattern of streaks. When the volcanoes became less active, impacts of small meteors on the leading hemisphere of the moon eliminated evidence of the streaks, while they remained visible on the trailing side.

Helene orbits at a position 60 degrees ahead of Dione, in the same orbit. There is no danger of collision, however, since the points 60 degrees ahead and behind any object (known as Lagrange points) exist as stable locations in any orbit. The moons will never get substantially closer or further away from each other.

1.111 Rhea - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Cassini
Date of Discovery......................1672
Alternate identification............Saturn V
Mass.................................2.49e21 kg  (4.17e-4 times that of Earth)
Radius...................................765 km  (0.11994 times that of Earth)
Surface gravity.......................0.234 m/s^2 (0.029 times that of Earth)
Escape velocity.......................0.659 km/s
Apparent semidiameter at 1 AU..........1.06 arcseconds
Average density........................1.33 g/cm^3
Magnitude at 1 AU.......................0.1
Geometric Albedo........................0.7

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........4.51750044 days
Orbital period......................4.51750044 days
Average orbital velocity..................8.49 km/sec.
Eccentricity.............................0.001
Inclination of orbit to Saturn’s equator...0.35 degrees
Distance from center of Saturn:
  Shortest........................526,510 km
  Average.........................527,040 km
  Greatest........................527,570 km
```

1.112 Rhea - Description

Rhea (pronounced REE-ah) was discovered by Cassini in 1684. In Greek mythology, Rhea was the sister and wife of Cronus. She was the mother of Demeter, Hades, Hera, Hestia, Poseidon, and Zeus. Rhea was known as "Ops" by the Romans.

Rhea is composed primarily of water ice, however since its density is somewhat higher than most of the other Saturnian satellites, up to 1/3 of its mass must be composed of silicate rock as well.

Since Rhea orbits Saturn in a "synchronous" orbit (always keeping the same side facing the planet), it is said to have a "leading" and "trailing" hemisphere. The leading hemisphere of Rhea is heavily cratered and uniformly bright, whereas the trailing hemisphere contains a network of bright streaks on a dark background. On this hemisphere, there are few craters. In these respects, Rhea is quite similar to Dione, only larger.

It is believed that shortly after its formation, Rhea was a geologically active moon. During this period, ice volcanoes covered the whole surface, leaving a pattern of streaks. When the volcanoes became less active, impacts of small meteors on the leading hemisphere of the moon eliminated evidence of the streaks, while they remained visible on the trailing side.

1.113 Hyperion - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Bond & Lassell
Date of Discovery......................1848
Alternate identification..........Saturn VII
Mass...............................1.77e19 kg  (2.96e-6 times that of Earth)
Dimensions.....................410x260x220 km  (0.03214 times that of Earth)
Surface gravity......................0.017 m/s^2 (2e-3  times that of Earth)
Escape velocity......................0.095 km/s
Apparent semidiameter at 1 AU..........0.28 arcseconds
Average density.........................1.4 g/cm^3
Magnitude at 1 AU......................4.63
Geometric Albedo........................0.3

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............chaotic
Orbital period......................21.2766088 days
Average orbital velocity..................5.07 km/sec.
Eccentricity............................0.104
Inclination of orbit to Saturn's equator...0.43 degrees
Distance from center of Saturn:
  Shortest.......................1,327,100 km
  Average........................1,481,100 km
  Greatest.......................1,635,100 km
```

1.114 Hyperion - Description

Hyperion (pronounced hi-PEER-ee-en) was discovered by Bond and Lassell in 1848. In Greek mythology, Hyperion was a Titan. He was the son of Uranus and Gaea, and the father of Helios.

Like most of the Saturnian moons, the low density of Hyperion implies that it is composed of water ice, with only a small amount of rock. But unlike the other moons, Hyperion has a small albedo of only 0.3. This indicates that it is covered by a thin layer of dark material. Some astronomers think that the coating may have originated from Phoebe.

Hyperion is the largest non-spherical object in the solar system, with dimensions of 410x260x220 km. Its rotation is chaotic - in other words, its spin rate and orientation is completely unpredictable. It is the only body in the solar system known to undergo chaotic rotation.

The largest crater on the surface of Hyperion is about 120 km in diameter and 10 km deep.

1.115 Iapetus - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer..........................Cassini
 Date of Discovery......................1671
 Alternate identification.........Saturn VIII
 Mass.............................1.88e21 kg  (3.15e-4 times that of Earth)
 Radius..............................730 km  (0.11446 times that of Earth)
 Surface gravity.....................0.235 m/s^2 (0.024 times that of Earth)
 Escape velocity.....................0.414 km/s
 Apparent semidiameter at 1 AU..........1.01 arcseconds
 Average density.....................1.21 g/cm^3
 Magnitude at 1 AU......................1.5
 Geometric Albedo.......................0.2 (*)

 Atmosphere............................None


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..........79.3301825 days
 Orbital period......................79.3301825 days
 Average orbital velocity..................3.27 km/sec.
 Eccentricity...........................0.02828
 Inclination of orbit to Saturn's equator..14.72 degrees
 Distance from center of Saturn:
   Shortest......................3,460,600 km
   Average.......................3,561,300 km
   Greatest......................3,662,000 km
* NOTE:  The leading and trailing hemispheres vary greatly in albedo.  The
albedo of the leading hemisphere is approximately 0.05, whereas that of the
trailing hemisphere is 0.5  The overall albedo of the satellite is 0.2.
```

1.116 Iapetus - Description

Iapetus (pronounced eye-AP-i-tus) was discovered by Cassini in 1671. In Greek mythology, Iapetus was a Titan, the son of Uranus. He was the father of Prometheus and Atlas, and was thought of as an ancestor of the human race.

Iapetus is composed almost entirely of water ice. It orbits Saturn in a synchronous orbit, keeping one side facing the planet at all times. As a result, one hemisphere can be said to be "leading" while the other is "trailing".

The appearance of the leading and trailing hemispheres of Iapetus varies greatly. The albedo of the leading hemisphere is approximately 0.05 (almost totally black) while that of the trailing hemisphere is 0.5. The difference is in fact so great that Cassini noted that he could only observe Iapetus while it was in orbit on one side of Saturn.

Astronomers do not know what causes this vast difference in albedo. Some feel that the dark hemisphere is coated with material from Phoebe, but the colors of the material don't quite match. Others feel that volcanism or some other process on Iapetus may be responsible for the appearance. Hard to explain from either point of view is the fact that the dividing line between the dark and bright hemispheres is unusually sharp.

1.117 Phoebe - Fast Facts

```
Physical Characteristics
------------------------
Discoverer........................Pickering
Date of Discovery......................1898
Alternate identification...........Saturn IX
Mass...............................4.0e18 kg  (6.69e-7 times that of Earth)
Radius...............................110 km  (0.01725 times that of Earth)
Surface gravity.......................0.022 m/s^2 (0.002 times that of Earth)
Escape velocity.......................0.049 km/s
Apparent semidiameter at 1 AU...........0.15 arcseconds
Average density.........................0.7 g/cm^3
Magnitude at 1 AU......................6.89
Geometric Albedo.......................0.06

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..................0.4 days
Orbital period.........................-550.48 days (*)
Average orbital velocity..................1.71 km/sec.
Eccentricity...........................0.16326
Inclination of orbit to Saturn's equator..175.3 degrees
Distance from center of Saturn:
  Shortest......................10,837,000 km
  Average.......................12,952,000 km
  Greatest......................15,067,000 km
```

* NOTE: Phoebe orbits around Saturn in a retrograde direction. As a result, its orbital period is given as a negative number of days.

1.118 Phoebe - Description

Phoebe (pronounced FEE-bee) was discovered by Pickering in 1898. In Greek mythology, Phoebe was the twin sister of Apollo. She was the virgin goddess of the hunt and the Moon.

Phoebe is a rather strange satellite of Saturn. It is almost 4 times more distant from the planet than the second furthest satellite, Iapetus. It is extremely dark, reflecting only 6% of the light that hits it. It orbits Saturn in a highly eccentric orbit, in a retrograde direction, and does not rotate synchronously (keeping the same face to Saturn at all times) as do most of the other Saturnian moons. Because of all these irregularities, many astronomers think that Phoebe may have been an asteroid captured by Saturn at some point in the past.

Phoebe is a reddish color and fairly spherical in shape. It is thought that material blasted off the surface of Phoebe by meteor impacts may be responsible for coating the surfaces of Hyperion and Iapetus.

1.119 Telesto - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........Reitsema, Smith & others
Date of Discovery.......................1981
Alternate identification.........Saturn XIII, 1980 S13
Mass................................unknown
Dimensions.........................34x28x26 km  (0.00267 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.02 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................8.9
Geometric Albedo........................0.5

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period................unknown
Orbital period............................1.8878 days
Average orbital velocity...................11.35 km/sec.
Eccentricity..............................unknown
Inclination of orbit to Saturn's equator..unknown
Distance from center of Saturn:
  Average..........................294,660 km
```

1.120 Telesto - Description

Telesto (pronounced tah-LESS-toe) was discovered in 1981 by Reitsema, Smith, Larson, and Fountain from ground-based observations made in 1980. It revolves around Saturn in the same orbit as Tethys, in a stable position (known as a Lagrange point) 60 degrees ahead of the latter.

In Greek mythology, Telesto was a daughter of Oceanus and Tethys.

Very little is known about Telesto.

1.121 Calypso - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer.............Pascu, Smith & others
 Date of Discovery......................1981
 Alternate identification..........Saturn XIV, 1980 S25
 Mass...............................unknown
 Dimensions.........................34x22x22 km  (0.00267 times that of Earth)
 Surface gravity.....................unknown
 Escape velocity.....................unknown
 Apparent semidiameter at 1 AU...........0.02 arcseconds
 Average density.....................unknown
 Magnitude at 1 AU.......................9.1
 Geometric Albedo........................0.6

 Atmosphere.............................None


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period................unknown
 Orbital period...........................1.8878 days
 Average orbital velocity...................11.35 km/sec.
 Eccentricity............................unknown
 Inclination of orbit to Saturn's equator..unknown
 Distance from center of Saturn:
   Average..........................294,660 km
```

1.122 Calypso - Description

Calypso (pronounced kah-LIP-so) was discovered in 1981 by Pascu, Smith, and others from ground-based observations made in 1980. The observations were made with prototype cameras designed for the Hubble Space Telescope.

Calypso revolves around Saturn in the same orbit as Tethys, in a stable position (known as a Lagrange point) 60 degrees behind the latter.

In Greek mythology, Calypso was a sea nymph who delayed Odysseus on her island for seven years.

Very little is known about Calypso.

1.123 Helene - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........P. Laques & J. Lecacheux
Date of Discovery.......................1980
Alternate identifications.........Saturn XII, Dione B, 1980 S6
Mass................................unknown
Dimensions.........................36x32x30 km  (0.00282 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.02 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................8.4
Geometric Albedo........................0.7

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period................unknown
Orbital period............................2.7369 days
Average orbital velocity...................10.03 km/sec.
Eccentricity...............................0.005
Inclination of orbit to Saturn's equator......0.2
Distance from center of Saturn:
  Shortest.........................375,510 km
  Average..........................377,400 km
  Greatest.........................379,290 km
```

1.124 Helene - Description

Helene (pronounced hel-EEN) was discovered in 1980 by P. Laques and J. Lecacheux from ground-based observations. It revolves around Saturn in the same orbit as Dione, in a stable position (known as a Lagrange point) 60 degrees ahead the latter.

Very little is known about Helene.

1.125 Pan - Fast Facts

```
Physical Characteristics
------------------------
Discoverer................Mark R. Showalter
Date of Discovery.......................1990
Alternate identification........Saturn XVIII, 1981 S13
Mass................................unknown
Radius.................................9.7 km  (0.00151 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.01 arcseconds
```

```
Average density.....................unknown
Magnitude at 1 AU...................unknown
Geometric Albedo........................0.5

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...............unknown
Orbital period...........................0.5750 days
Average orbital velocity..................16.75 km/sec.
Eccentricity.............................unknown
Inclination of orbit to Saturn's equator..unknown
Distance from center of Saturn:
  Average.........................133,583 km
```

1.126 Pan - Description

Pan was discovered by Mark Showalter on July 16, 1990 in photographs taken 9 years earlier by the Voyager probes. In a painstaking survey through 30,000 images of Saturn's rings, Pan only appeared in 11 pictures.

In Greek mythology, Pan was the god of woods, fields, and flocks. He had a human torso and head, with the legs, horns, and ears of a goat.

Pan orbits within the Encke Gap in Saturn's rings, and is responsible for keeping the gap open. Before Pan's discovery, an analysis of ripple patterns in the edge of Saturn's "A" ring predicted its size and location. It is suspected that other small moons like Pan may still wait to be discovered in the Voyager images.

Very little is known about Pan.

1.127 Atlas - Fast Facts

```
Physical Characteristics
------------------------
Discoverer........................R. Terrile
Date of Discovery......................1980
Alternate identification...........Saturn XV, 1980 S28
Mass................................unknown
Dimensions............................40x20 km  (0.00314 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.03 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................8.4
Geometric Albedo........................0.9

Atmosphere.............................None
```

```
Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period................unknown
Orbital period.............................0.6019 days
Average orbital velocity...................16.63 km/sec.
Eccentricity...............................0.000
Inclination of orbit to Saturn's equator......0.3
Distance from center of Saturn:
  Shortest.........................137,670 km
  Average..........................137,670 km
  Greatest.........................137,670 km
```

1.128 Atlas - Description

Atlas was discovered by R. Terrile in 1980 in photographs taken by Voyager 1.

In Greek mythology, Atlas was a Titan condemned by Zeus to support the heavens on his shoulders. He was the son of Iapetus and brother of Prometheus and Epimetheus.

Atlas orbits near the outer edge of Saturn's "A" ring, and is classified as a "shepherd moon". This means that it is responsible for keeping the particles confined to the ring.

Very little is known about Atlas.

1.129 Prometheus - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...............S. Collins & others
Date of Discovery......................1980
Alternate identification..........Saturn XVI, 1980 S27
Mass................................2.7e17 kg  (4.52e-8 times that of Earth)
Dimensions........................145x85x65 km  (0.01137 times that of Earth)
Surface gravity......................0.0025 m/s^2 (3e-4  times that of Earth)
Escape velocity.......................0.021 km/sec
Apparent semidiameter at 1 AU...........0.10 arcseconds
Average density.........................0.7 g/cm^3
Magnitude at 1 AU.......................6.4
Geometric Albedo........................0.6

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period................unknown
Orbital period.............................0.6130 days
Average orbital velocity...................16.54 km/sec.
Eccentricity...............................0.003
```

```
Inclination of orbit to Saturn's equator......0.0
Distance from center of Saturn:
  Shortest........................138,935 km
  Average.........................139,353 km
  Greatest........................139,771 km
```

1.130 Prometheus - Description

Prometheus (pronounced pra-MEE-thee-us) was discovered by S. Collins and others in 1980 from photographs taken by Voyager 1.

In Greek mythology, Prometheus was the Titan who stole fire from Olympus and gave it to mankind. For this act, he was punished heavily by Zeus. He is the son of Iapetus, and the brother of Atlas and Epimetheus.

A number of ridges, valleys, and craters were visible in the Voyager images of Prometheus. From its low density and high albedo, it seems that Prometheus is a porous, icy object.

Prometheus acts as a shepherd satellite for the "F" ring of Saturn. This means that its gravitational influence keeps particles confined to the ring and limits their tendency to spread out.

1.131 Pandora - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..............S. Collins & others
Date of Discovery......................1980
Alternate identification.........Saturn XVII, 1980 S26
Mass...............................2.2e17 kg  (3.68e-8 times that of Earth)
Dimensions.......................114x84x62 km  (0.00893 times that of Earth)
Surface gravity......................0.0021 m/s^2 (2e-4  times that of Earth)
Escape velocity.......................0.019 km/sec
Apparent semidiameter at 1 AU..........0.08 arcseconds
Average density........................0.7 g/cm^3
Magnitude at 1 AU......................6.4
Geometric Albedo.......................0.9

Atmosphere............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period................unknown
Orbital period...........................0.6285 days
Average orbital velocity...................16.39 km/sec.
Eccentricity...............................0.004
Inclination of orbit to Saturn's equator......0.0
Distance from center of Saturn:
  Shortest........................141,100 km
  Average.........................141,700 km
```

```
   Greatest.........................142,300 km
```

1.132 Pandora - Description

Pandora (pronounced pan-DOR-uh) was discovered by S. Collins and others in 1980 from photographs taken by Voyager 1.

In Greek mythology, Pandora was the first woman. She was given to humans by Zeus as a punishment for Prometheus' theft of fire. Given a box containing all the evils in the world, she opened it out of curiosity and released them to plague humankind. She was the wife of Epimetheus.

Pandora is the outer shepherd satellite of Saturn's "F" ring. Thus, its gravitational influence keeps particles confined to the ring and limits their tendency to spread out.

This satellite is quite heavily cratered, with at least two craters greater than 30 km in diameter. But unlike nearby Prometheus, it shows no linear ridges or valleys. From its low density and high albedo, it seems that Pandora is a porous, icy object.

1.133 Epimetheus - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverers.......Walker, Larson, & Fountain
 Date of Discovery......................1980
 Alternate identification...........Saturn XI, 1980 S3
 Mass...............................5.6e17 kg  (9.37e-8 times that of Earth)
 Dimensions......................144x108x98 km  (0.01129 times that of Earth)
 Surface gravity.......................0.0032 m/s^2 (3e-4  times that of Earth)
 Escape velocity.......................0.026 km/sec
 Apparent semidiameter at 1 AU...........0.10 arcseconds
 Average density.........................0.7 g/cm^3
 Magnitude at 1 AU.......................5.4
 Geometric Albedo........................0.8

 Atmosphere..............................None


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period.................0.6942 days
 Orbital period.............................0.6942 days
 Average orbital velocity...................15.87 km/sec.
 Eccentricity................................0.009
 Inclination of orbit to Saturn's equator.....0.34
 Distance from center of Saturn:
   Shortest........................150,059 km
   Average.........................151,422 km
   Greatest........................152,785 km
```

1.134 Epimetheus - Description

Epimetheus (pronounced ep-eh-MEE-thee-us) was discovered by R. Walker, Larson, and Fountain from ground observations in 1978. It was later confirmed by photographs taken by the Voyager probes in 1980.

In Greek mythology, Epimetheus was the son of Iapetus and the brother of Atlas and Prometheus. He married Pandora.

This irregularly-shaped moon is covered with craters, grooves, valleys, and ridges. From its low density and high albedo, it appears as though Epimetheus is a porous, icy object. The vertical dark band on the left side of the moon in the photograph is not a variation in surface composition. Instead, it is merely the shadow of Saturn’s "F" ring.

Epimetheus shares an interesting orbit with Janus. Once every four years or so they approach within 50 km of each other. When this occurs, they exchange momentum with each other and switch orbits (the inner satellite becomes the outer and vice-versa). It is thought that they may have once been a single body split into two by some force early in the history of the solar system.

Though Epimetheus was confirmed in 1980, it may have been photographed in 1966 during a time when the rings of Saturn were edge-on as viewed from the Earth. At the time the object was named "Janus", though as the two moons are in similar orbits, it is not known which of the two was actually photographed.

1.135 Janus - Fast Facts

```
Physical Characteristics
------------------------
Discoverers.....Dollfuss, Larson, & Fountain
Date of Discovery........................1966
Alternate identification............Saturn X, 1980 S1
Mass...............................2.01e18 kg  (3.36e-7 times that of Earth)
Dimensions.......................196x192x150 km  (0.01537 times that of Earth)
Surface gravity......................0.0036 m/s^2 (4e-4  times that of Earth)
Escape velocity.......................0.037 km/sec
Apparent semidiameter at 1 AU...........0.14 arcseconds
Average density.........................0.7 g/cm^3
Magnitude at 1 AU.......................4.4
Geometric Albedo........................0.8

Atmosphere..............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period.................0.6945 days
Orbital period.............................0.6945 days
Average orbital velocity...................15.85 km/sec.
Eccentricity...............................0.007
Inclination of orbit to Saturn’s equator.....0.14
Distance from center of Saturn:
  Shortest........................150,412 km
```

```
   Average.........................151,472 km
   Greatest........................152,532 km
```

1.136 Janus - Description

Janus (pronounced JAY-nus) may have been photographed by Audouin Dollfus in 1966 during a time when the rings of Saturn appeared edge-on from the Earth. However, when the Voyager probes went to the Saturnian system 14 years later, their photographs revealed that there were actually two satellites sharing almost the same orbit - Janus and Epimetheus. Once every four years or so, they approach to within 50 km of each other. When this occurs, they exchange momentum and switch orbits (the inner satellite becomes the outer and vice-versa). It is thought that they may have once been a single body split into two by some force early in the history of the solar system.

Due to this interesting orbit, it is unknown whether Dollfus succeeded photographing Janus or Epimetheus in 1966.

In Greek mythology, Janus was the god of gates and doorways. He is usually depicted with two faces looking in opposite directions. The English word "January" derives its name from this god.

This irregularly-shaped moon is covered with craters and a few grooves and valleys. From its low density and high albedo, it appears as though Janus is a porous, icy object.

1.137 Uranus - Fast Facts

```
 Physical Characteristics
 ------------------------
 Mass..............................8.625e25 kg  (14.500 times that of Earth)
 Equatorial radius.....................25559 km  (4.0073 times that of Earth)
 Polar radius..........................24973 km  (3.9286 times that of Earth)
 Surface gravity........................8.87 m/s^2 (0.90 times that of Earth)
 Escape velocity........................21.2 km/s
 Apparent semidiameter at 1 AU..........35.50 arcseconds
 Average density........................1.29 g/cm^3
 Average temperature at 1 atmosphere.....-215 degrees C
 Magnitude at 1 AU.....................-7.19
 Geometric Albedo.......................0.51

 Atmospheric Composition (by number of atoms):
     Hydrogen............................83%
     Helium..............................15%
     Methane..............................2%
     Acetylene, other hydrocarbons......trace

 Number of known satellites...............15

                Cordelia       Juliet         Miranda
                Ophelia        Portia         Ariel
                Bianca         Rosalind       Umbriel
```

```
                 Cressida       Belinda        Titania
                 Desdemona      Puck           Oberon


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period, System III...17.2 hours
 Inclination of equator to orbit.........97.86 degrees (*)
 Orbital period (length of year)........83.747 years
 Average orbital velocity..............6.8352 km/sec.
 Eccentricity......................0.0462958985125
 Inclination of orbit to ecliptic.....0.773196 degrees
 Distance from Sun:
   Shortest.....................2,741,936,000 km (18.32871 AU)
   Average......................2,875,038,000 km (19.21844 AU)
   Greatest.....................3,008,054,000 km (20.10760 AU)
* NOTE:  Uranus is unique in the fact that its axis of rotation does not lie in
approximately the same direction as that of the other planets.  Instead, when
viewed from the orientation of the Earth, it appears to lie on its side and
roll along in its orbit.
```

1.138 Uranus - Mythology

Uranus was named for the earliest Greek and Roman god. He was the son and husband of Gaea, the Earth. He was the father of Cronus, the Cyclops, and the Titans.

Uranus feared his children and imprisoned them deep within the Earth after their birth. In revenge, Gaea and Cronus attacked Uranus with a sickle while he slept. Because of his wound, he became separated forever from Gaea and took refuge in the heavens. The Greeks and Romans used this myth to explain the division between the Earth and the sky.

After Uranus left the Earth, his duties were taken over by his grandson Jupiter.

1.139 Uranus - Discovery

Uranus is the first planet to have been discovered in modern times. On March 13, 1781, Sir William Herschel was searching the sky with his telescope when he accidentally stumbled across Uranus. At first, he thought it was a comet, but closer examination revealed it to be a large planet at great distance. Herschel named the object "Georgium Sidus" (the Georgian planet) in honor of his patron King George III of England. Many others simply called it "Herschel". Johann Bode proposed the name "Uranus" to conform to the theme of classical mythology used in the names for the other planets, but it wasn’t until as late as 1850 that the name came into common use.

Herschel wasn’t the first person to observe Uranus - the earliest known sighting was by Flamsteed in 1690. However, all previous astronomers had just dismissed the object as another star (Flamsteed even gave it an identification - 34 Tauri!). There are at least 15 other known sightings of the planet before

Herschel recognized it as such.

1.140 Uranus - Exploration

Since Uranus is located at such a great distance, telescopes on Earth are not large enough to reveal much information about the planet. Only one spacecraft has ever been sent to Uranus - Voyager 2. Despite the fact that the spacecraft flew to within 81,500 km of the cloudtops, a surprising lack of detail was revealed to Voyager's cameras.

Because the light levels at the distance of Uranus and beyond are so low, relatively long exposure times were required by Voyager's camera. Since the spacecraft moved so quickly through the Uranian system, the images would have been badly blurred if special precautions were not taken. A special rotating platform for the camera was not operational, so mission controllers rotated the entire spacecraft throughout an exposure keeping the camera pointed at its target. Due to these measures, the images taken at Uranus are actually the sharpest of the entire mission.

1.141 Uranus - Physical Features

Uranus is the third largest planet in the solar system. Only Jupiter and Saturn are larger.

Most of our current knowledge about Uranus comes from information returned by the highly successful Voyager 2 spacecraft. There are currently no plans to send another spacecraft to this gas giant.

View Uranus, as seen from Voyager 2 leaving the planet

Structure of Uranus

Unlike Jupiter and Saturn, which are composed of mostly hydrogen, Uranus only contains about 15% hydrogen and a few percent helium. Most of it is locked up in the planet's thick atmosphere. Beneath this, a more or less homogeneous mixture of ices, rock, and gas is believed to exist. In many ways, Uranus is believed to be similar to the cores of Jupiter and Saturn, without the massive layer of liquid metallic hydrogen surrounding it.

Magnetic field

Like the other gas giants, Uranus was observed to have a magnetic field. However, scientists are at a bit of a loss to explain how its magnetic field is generated. It was originally assumed that an electrically conducting ocean of water and ammonia lay beneath the atmosphere, providing the mechanisms necessary to generate such a field. However, no such layer was detected by Voyager 2.

The magnetic field of Uranus is interesting in at least one other aspect as well. For most of the planets in the solar system possessing magnetic fields, the magnetic field axis points in more or less the same direction as the planet’s axis of rotation. But at Uranus, the angle between the two axes is 59 degrees - and the magnetic field axis passes more than 7,600 km from the center of the planet. Much work remains to be done before scientists will be able to postulate a plausible mechanism.

Orientation of the planet

The axis of rotation for most of the planets in the solar system is more or less perpendicular to the ecliptic. However, this is not the case with Uranus. When Voyager 2 made its flyby of the planet, the south pole was pointed almost directly at the Sun. Uranus is tipped over on its side, and almost seems to "roll" along in its orbit around the Sun.

As a result of this bizarre orientation, for half a Uranian year (83.7 Earth years), one of the poles receives sunlight continually while the other is shrouded in perpetual darkness. Eventually, the planet reaches a location where the Sun appears over the equator and the roles of the poles reverse.

Since Voyager 2 observed the planet when the Sun was over the south pole of Uranus, it was expected that this pole should be the hottest region on the planet. But astronomers were surprised to learn that Uranus was hotter at the equator. The processes resulting in this phenomenon are unknown.

An interesting effect of the orientation of the planet and the angle of the magnetic axis is that the magnetotail of Uranus is twisted in a long corkscrew shape behind the planet.

Appearance of Uranus

When Voyager 2 began returning pictures of Uranus, scientists were surprised by the lack of detail in the atmosphere. When Jupiter and Saturn were encountered, a wealth of detail could be seen in the clouds encircling the planet.

Under radical computer image enhancement of the Voyager 2 photographs, rapidly moving bands of clouds were detected, though the bands were extremely faint. Winds in the mid latitudes of the planet moved at speeds between 140 to 570 km/hour, in the direction of rotation of the planet. On the other hand, winds near the equator moved at speeds of approximately 360 km/hour in the opposite direction.

Recent observations by the Hubble Space Telescope have revealed larger and more pronounced features. Some scientists feel that the differences can be explained by seasonal effects; since the time Voyager 2 flew past the planet, the Sun has been at a lower latitude. This produces a stronger day/night effect than when the Sun is nearer one of the poles, as it was during Voyager 2’s encounter.

Uranus appears a blue-green in color. This is due to the absorption of red light by methane in the upper atmosphere. Beneath this methane layer, there may be more distinct cloud bands, as had been seen at Jupiter and Saturn.

View Uranus, as seen from Voyager 2

1.142 Uranus' rings

Like all the gas giant planets, Uranus has rings. Nine of the eleven principal ring systems were discovered from ground-based observations in 1977. While observing Uranus occult a star, small variations in the star's brightness were recorded, even when Uranus was still some distance away. This was explained as ring material surrounding Uranus occulting the star before the planet. In such a way, the rings' presence could be deduced even without physically seeing them. The finding was significant, since before the discovery astronomers didn't know if planetary rings were a commonplace occurrence or unique to Saturn.

The rings are quite dark, consisting of particles ranging in size from fine dust to ice boulders up to 10 metres in diameter. There are 11 principal rings, the brightest of which is known as "Epsilon". In most places, the ring formations are less than 100 metres thick. It is thought that the rings are less than 100 million years old and were likely formed from the destruction of a small moon when it collided with a meteoroid or comet.

In addition to the principal rings, there are a large number of narrow rings, and even incomplete rings (ring arcs).

The rings of Uranus can be summarized by the following table:

Name	Distance (km)	Width (km)
1986U2R	38,000	2,500
6	41,840	1-3
5	42,230	2-3
4	42,580	2-3
Alpha	44,720	7-12
Beta	45,670	7-12
Eta	47,190	0-2
Gamma	47,630	1-4
Delta	48,290	3-9
1986U1R	50,020	1-2
Epsilon	51,140	20-100

NOTE: Distances are measured from the center of the planet.

Because Uranus' north pole points in a different direction than the north pole of our Earth, the angle at which we view the rings varies with time throughout Uranus' orbit around the Sun. As a result, our view of the rings changes from virtually face-on to edge-on at different times throughout the Uranian year.

In the following picture, the nine principal rings of Uranus can be seen, as well as the dust surrounding them. It was taken as Voyager 2 was looking back through the ring system toward the Sun. Due to the 96 second exposure required, and the fact that the spacecraft was moving quickly past Uranus, the camera was required to move while taking the picture so that the rings remained in focus. As a result, stars in the background appear as short streaks.

View Uranian rings

"Shepherding moons" were discovered at Uranus, as they were at Saturn. These moons use their gravitational influence to keep rings together, not allowing particles to stray too far from the central condensation. Ophelia and Cordelia were discovered in the following picture. It is clear that they act as shepherding moons for the Epsilon ring. The moons appear as short arcs due to their movement in orbit around Uranus during the duration of the exposure.

View shepherding satellites Ophelia and Cordelia

1.143 Uranus - Observing the Planet

At its brightest, Uranus reaches a magnitude of 6.0. This means that it is just barely visible to the naked eye from a dark location. Use "The Digital Universe" to print a star chart of the region around Uranus, and then use binoculars or a telescope to identify the planet.

In a telescope, Uranus will appear as a tiny, bluish-green disk. Since Voyager 2 didn't find many details on the surface of the planet at a distance of 81,500 km, don't be disappointed if you can't find details from the Earth (at an average distance of almost 3 billion km!). Nevertheless, it is always exciting to spend some time hunting around the sky and verify that you found Uranus.

If you have a large telescope, you could try to see if you could detect any of Uranus' moons. Again, "The Digital Universe" can help you determine where to look. Although the software accurately shows the orientation of Uranus' rings, they are extremely faint and will not be visible with an amateur telescope. In fact, even the Hubble Space Telescope has difficulty seeing them.

1.144 Uranus - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience. For images of Uranus' moons, please follow the links to the satellite of interest, provided at the introductory screen for information on the planet.

Featureless disk of Uranus, as seen by Voyager 2
Uranian ring system
Image of Epsilon ring and ring shepherds
View from Voyager 2 leaving Uranus

1.145 Miranda - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...........................Kuiper
Date of Discovery......................1948
Alternate identification...........Uranus V
Mass..............................6.33e19 kg  (1.06e-5 times that of Earth)
Radius.............................235.8 km  (0.03697 times that of Earth)
Surface gravity....................0.076 m/s^2 (0.008 times that of Earth)
Escape velocity....................0.189 km/s
Apparent semidiameter at 1 AU..........0.33 arcseconds
```

```
Average density........................1.15 g/cm^3
Magnitude at 1 AU.......................3.6
Geometric Albedo........................0.27

Atmosphere..............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........1.41347925 days
Orbital period.......................1.41347925 days
Average orbital velocity..................6.68 km/sec.
Eccentricity............................0.0027
Inclination of orbit to Uranus' equator.....4.2 degrees
Distance from center of Uranus:
  Shortest........................129,040 km
  Average.........................129,390 km
  Greatest........................129,740 km
```

1.146 Miranda - Description

Miranda (pronounced mih-RAN-dah) was discovered by Kuiper in 1948. The moons of Uranus are named after characters in stories by Shakespeare or Pope, unlike the moons of other planets (which are named after mythological figures). Miranda is the daughter of Prospero the magician in Shakespeare's "The Tempest".

Due to the trajectory of Voyager 2 at Uranus, the only satellite which could be closely approached was Miranda. It was found to be composed of approximately equal proportions of rock and ice. The terrain was heavily cratered, with strange valleys and cliffs covering the surface.

Prior to Voyager's encounter, scientists did not expect to find moons with much internal activity at Uranus' distance from the Sun, so Miranda's surface was a great surprise. It is now believed that Miranda was shattered and reassembled many times before assuming its present form.

Details as small as a few hundred metres can be seen in some of the Voyager pictures of Miranda.

1.147 Ariel - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Lassell
Date of Discovery......................1851
Alternate identification...........Uranus I
Mass...............................1.35e21 kg  (2.26e-4 times that of Earth)
Radius...............................578.9 km  (0.09077 times that of Earth)
Surface gravity.......................0.269 m/s^2 (0.027 times that of Earth)
Escape velocity.......................0.558 km/s
Apparent semidiameter at 1 AU...........0.80 arcseconds
Average density........................1.56 g/cm^3
```

```
Magnitude at 1 AU......................1.45
Geometric Albedo.......................0.34

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........2.52037935 days
Orbital period.......................2.52037935 days
Average orbital velocity..................5.52 km/sec.
Eccentricity............................0.0034
Inclination of orbit to Uranus' equator.....0.3 degrees
Distance from center of Uranus:
  Shortest........................190,370 km
  Average.........................191,020 km
  Greatest........................191,670 km
```

1.148 Ariel - Description

Ariel (pronounced AIR-ee-el) was discovered by Lassell in 1851. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Ariel is a mischievous spirit in Shakespeare's "The Tempest".

Ariel is similar in appearance to Titania. It is composed of approximately equal proportions of rock and ice. The terrain is heavily cratered, with many valleys and cliffs hundreds of kilometres long and up to 10 km deep. Some ridges in the valleys were observed, thought to be upwellings of ice. Some canyon floors appear to have been smoothed over by a fluid. This could not have been water (Ariel is much too cold for liquid water to exist), but it could have been liquid forms of ammonia, methane, or carbon monoxide.

1.149 Umbriel - Fast Facts

```
Physical Characteristics
------------------------
Discoverer..........................Lassell
Date of Discovery......................1851
Alternate identification...........Uranus II
Mass..............................1.17e21 kg  (1.96e-4 times that of Earth)
Radius................................584.7 km  (0.09168 times that of Earth)
Surface gravity.......................0.228 m/s^2 (0.023 times that of Earth)
Escape velocity.......................0.517 km/s
Apparent semidiameter at 1 AU...........0.81 arcseconds
Average density........................1.52 g/cm^3
Magnitude at 1 AU......................2.10
Geometric Albedo.......................0.18

Atmosphere.............................None
```

```
Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period............4.1441772 days
Orbital period........................4.1441772 days
Average orbital velocity..................4.67 km/sec.
Eccentricity.............................0.0050
Inclination of orbit to Uranus' equator....0.36 degrees
Distance from center of Uranus:
  Shortest.........................264,970 km
  Average..........................266,300 km
  Greatest.........................267,630 km
```

1.150 Umbriel - Description

Umbriel (pronounced UM-bree-el) was discovered by Lassell in 1851. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Umbriel is a character in "The Rape of the Lock" by Pope.

Umbriel is similar in appearance to Oberon. It is composed of approximately equal proportions of rock and ice. The terrain is heavily cratered - more so than most of the other Uranian moons. This likely indicates that the surface has undergone little geological change since the moon's formation.

The surface material of Umbriel is very dark, reflecting only 18% of the light which hits it. Near the top of the picture provided with "The Digital Universe" is a bright feature called the "flourescent cheerio". It is probably the floor of a crater.

1.151 Titania - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.........................Herschel
Date of Discovery......................1787
Alternate identification..........Uranus III
Mass................................3.49e21 kg  (5.84e-4 times that of Earth)
Radius...............................788.9 km  (0.12369 times that of Earth)
Surface gravity......................0.374 m/s^2 (0.038 times that of Earth)
Escape velocity......................0.768 km/s
Apparent semidiameter at 1 AU..........1.10 arcseconds
Average density........................1.70 g/cm^3
Magnitude at 1 AU......................1.02
Geometric Albedo.......................0.27

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period............8.7058717 days
Orbital period........................8.7058717 days
```

```
Average orbital velocity..................3.65 km/sec.
Eccentricity............................0.0022
Inclination of orbit to Uranus' equator....0.14 degrees
Distance from center of Uranus:
  Shortest.........................434,950 km
  Average..........................435,910 km
  Greatest.........................436,870 km
```

1.152 Titania - Description

Titania (pronounced ty-TAY-nee-uh) was discovered by Herschel in 1787. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Titania appears in Shakespeare's "A Midsummer Night's Dream" as the wife of Oberon and queen of the fairies.

Titania is similar in appearance to Ariel. It is composed of approximately equal proportions of rock and ice. The terrain is heavily cratered, with many valleys and cliffs hundreds of kilometres long and up to 10 km deep. It is thought that many of these features formed when cracks appeared as the moon froze. There is some evidence to suggest that Titania was geologically active in the past.

1.153 Oberon - Fast Facts

```
Physical Characteristics
------------------------
Discoverer.........................Herschel
Date of Discovery......................1787
Alternate identification...........Uranus IV
Mass...............................3.03e21 kg  (5.07e-4 times that of Earth)
Radius.............................761.4 km  (0.11938 times that of Earth)
Surface gravity....................0.349 m/s^2 (0.036 times that of Earth)
Escape velocity....................0.729 km/s
Apparent semidiameter at 1 AU...........1.06 arcseconds
Average density....................1.64 g/cm^3
Magnitude at 1 AU......................1.23
Geometric Albedo.......................0.24

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period...........13.4632389 days
Orbital period.......................13.4632389 days
Average orbital velocity..................3.15 km/sec.
Eccentricity............................0.0008
Inclination of orbit to Uranus' equator....0.10 degrees
Distance from center of Uranus:
  Shortest.........................583,050 km
  Average..........................583,520 km
```

```
   Greatest..........................583,990 km
```

1.154 Oberon - Description

Oberon (pronounced OH-buh-ron) was discovered by Herschel in 1787. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Oberon appears in Shakespeare's "A Midsummer Night's Dream" as the husband of Titania and king of the fairies.

Oberon is similar in appearance to Umbriel. It is composed of approximately equal proportions of rock and ice. The terrain is more heavily cratered than most of the other Uranian moons. This likely indicates that the surface has undergone little geological change since the moon's formation. Some craters have rays of ejecta emanating from them. Others have a dark material covering their floor. It is thought that some material might have upwelled into the basin upon impact of the object creating the crater.

The southern hemisphere of Oberon is covered with faults. The picture provided with "The Digital Universe" shows several of these faults and impact craters. On the lower left limb of the satellite, a mountain 6 km high can be seen.

1.155 Cordelia - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer...................Voyager 2 team
 Date of Discovery......................1986
 Alternate identification...........Uranus VI, 1986 U7
 Mass...............................unknown
 Radius...................................13 km  (0.00204 times that of Earth)
 Surface gravity.....................unknown
 Escape velocity.....................unknown
 Apparent semidiameter at 1 AU...........0.02 arcseconds
 Average density.....................unknown
 Magnitude at 1 AU......................11.4
 Geometric Albedo.......................0.07

 Atmosphere.............................None


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..............unknown
 Orbital period........................0.335033 days
 Average orbital velocity.................10.80 km/sec.
 Eccentricity...........................<0.001
 Inclination of orbit to Uranus' equator....0.14 degrees
 Distance from center of Uranus:
   Average...........................49,770 km
```

1.156 Cordelia - Description

Cordelia (pronounced kor-DEE-lee-uh) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Cordelia was the daughter of King Lear in Shakespeare's play "King Lear".

Cordelia is one of the smallest moons in the solar system. It acts as the inner shepherd satellite for the Epsilon ring of Uranus, using its gravitational influence to keep ring particles from straying too close to the planet.

Very little is known about Cordelia.

1.157 Ophelia - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1986
Alternate identification..........Uranus VII, 1986 U8
Mass..............................unknown
Radius...................................16 km  (0.00251 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.02 arcseconds
Average density.....................unknown
Magnitude at 1 AU......................11.1
Geometric Albedo.......................0.07

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.376409 days
Average orbital velocity.................10.80 km/sec.
Eccentricity.............................0.010
Inclination of orbit to Uranus' equator....0.09 degrees
Distance from center of Uranus:
  Shortest...........................53,250 km
  Average............................53,790 km
  Greatest...........................54,330 km
```

1.158 Ophelia - Description

Ophelia (pronounced oh-FEE-lee-uh) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Ophelia was the daughter of Polonius in Shakespeare's play "Hamlet".

Ophelia is one of the smallest moons in the solar system. It acts as the outer shepherd satellite for the Epsilon ring of Uranus, using its gravitational influence to keep ring particles from straying too far from the planet.

Very little is known about Ophelia.

1.159 Bianca - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer...................Voyager 2 team
 Date of Discovery......................1986
 Alternate identification.........Uranus VIII, 1986 U9
 Mass...............................unknown
 Radius...................................22 km  (0.00345 times that of Earth)
 Surface gravity.....................unknown
 Escape velocity.....................unknown
 Apparent semidiameter at 1 AU...........0.03 arcseconds
 Average density.....................unknown
 Magnitude at 1 AU......................10.3
 Geometric Albedo.......................0.07

 Atmosphere.............................None


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period.............unknown
 Orbital period........................0.434577 days
 Average orbital velocity..................9.90 km/sec.
 Eccentricity............................<0.001
 Inclination of orbit to Uranus' equator....0.16 degrees
 Distance from center of Uranus:
   Average............................59,170 km
```

1.160 Bianca - Description

Bianca (pronounced bee-AN-kuh) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Bianca appears in Shakespeare's "The Taming of the Shrew" as the sister of Katherine.

Very little is known about Bianca.

1.161 Cressida - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1986
Alternate identification..........Uranus IX, 1986 U3
Mass................................unknown
Radius..................................33 km  (0.00517 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU..........0.05 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................9.5
Geometric Albedo.......................0.07

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period.............unknown
Orbital period........................0.463570 days
Average orbital velocity..................9.69 km/sec.
Eccentricity...........................<0.001
Inclination of orbit to Uranus' equator....0.04 degrees
Distance from center of Uranus:
  Average...........................61,780 km
```

1.162 Cressida - Description

Cressida (pronounced cress-EE-duh) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Cressida appears as one of the title characters in Shakespeare's play "Troilus and Cressida".

Very little is known about Cressida.

1.163 Desdemona - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1986
Alternate identification...........Uranus X, 1986 U6
Mass................................unknown
Radius..................................29 km  (0.00455 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU..........0.04 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................9.8
```

```
Geometric Albedo.......................0.07

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.473651 days
Average orbital velocity..................9.62 km/sec.
Eccentricity............................<0.001
Inclination of orbit to Uranus' equator....0.16 degrees
Distance from center of Uranus:
  Average...........................62,680 km
```

1.164 Desdemona - Description

Desdemona (pronounced dez-dah-MOE-nah) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Desdemona appears as the wife of Othello in Shakespeare's play "Othello".

Very little is known about Desdemona.

1.165 Juliet - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1986
Alternate identification...........Uranus XI, 1986 U2
Mass...............................unknown
Radius..................................42 km  (0.00659 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.06 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................8.8
Geometric Albedo.......................0.07

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.493066 days
Average orbital velocity..................9.50 km/sec.
Eccentricity............................<0.001
Inclination of orbit to Uranus' equator....0.06 degrees
Distance from center of Uranus:
```

```
   Average............................64,350 km
```

1.166 Juliet - Description

Juliet (pronounced JOO-lee-et) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Juliet is named after the famous heroine in "Romeo and Juliet", by Shakespeare.

Very little is known about Juliet.

1.167 Portia - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer...................Voyager 2 team
 Date of Discovery......................1986
 Alternate identification..........Uranus XII, 1986 U1
 Mass...............................unknown
 Radius..................................55 km  (0.00862 times that of Earth)
 Surface gravity......................unknown
 Escape velocity......................unknown
 Apparent semidiameter at 1 AU...........0.08 arcseconds
 Average density......................unknown
 Magnitude at 1 AU.......................8.3
 Geometric Albedo........................0.07

 Atmosphere..............................None


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..............unknown
 Orbital period.........................0.513196 days
 Average orbital velocity..................9.38 km/sec.
 Eccentricity............................<0.001
 Inclination of orbit to Uranus' equator....0.09 degrees
 Distance from center of Uranus:
   Average............................66,090 km
```

1.168 Portia - Description

Portia (pronounced POR-shya) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Portia appears in Shakespeare's play "Merchant of Venice" as a rich heiress.

Very little is known about Portia.

1.169 Rosalind - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1986
Alternate identification.........Uranus XIII, 1986 U4
Mass...............................unknown
Radius..................................27 km  (0.00423 times that of Earth)
Surface gravity....................unknown
Escape velocity....................unknown
Apparent semidiameter at 1 AU...........0.04 arcseconds
Average density....................unknown
Magnitude at 1 AU.......................9.8
Geometric Albedo.......................0.07

Atmosphere.............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period.............unknown
Orbital period........................0.558459 days
Average orbital velocity..................9.12 km/sec.
Eccentricity...........................<0.001
Inclination of orbit to Uranus' equator....0.28 degrees
Distance from center of Uranus:
  Average...........................69,940 km
```

1.170 Rosalind - Description

Rosalind (pronounced ROZ-a-lind) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Rosalind appears in Shakespeare's play "As You Like It" as the daughter of a banished Duke.

Very little is known about Rosalind.

1.171 Belinda - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1986
Alternate identification..........Uranus XIV, 1986 U5
Mass...............................unknown
Radius..................................34 km  (0.00533 times that of Earth)
Surface gravity....................unknown
Escape velocity....................unknown
Apparent semidiameter at 1 AU...........0.05 arcseconds
Average density....................unknown
```

```
Magnitude at 1 AU.......................9.4
Geometric Albedo........................0.07

Atmosphere..............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period.........................0.623525 days
Average orbital velocity..................8.78 km/sec.
Eccentricity............................<0.001
Inclination of orbit to Uranus' equator....0.03 degrees
Distance from center of Uranus:
  Average............................75,260 km
```

1.172 Belinda - Description

Belinda (pronounced beh-LIN-da) was discovered by the Voyager 2 team in 1986. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Belinda appears as the heroine in Pope's play "The Rape of the Lock".

The photograph of Belinda taken by Voyager 2 shows part of the bright Epsilon ring of Uranus.

Very little is known about Belinda.

1.173 Puck - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1985
Alternate identification..........Uranus XV, 1985 U1
Mass..............................unknown
Radius...................................77 km  (0.01207 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.11 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................7.5
Geometric Albedo........................0.07

Atmosphere..............................None


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period.........................0.761832 days
```

```
 Average orbital velocity..................8.21 km/sec.
 Eccentricity............................<0.001
 Inclination of orbit to Uranus' equator....0.31 degrees
 Distance from center of Uranus:
   Average...........................86,010 km
```

1.174 Puck - Description

Puck was discovered by the Voyager 2 team in 1985. The moons of Uranus are named after characters in stories by Shakespeare or Alexander Pope, unlike the moons of other planets (which are named after mythological figures). Puck appears as a mischievous fairy in Shakespeare's "A Midsummer Night's Dream".

Of the 10 moons discovered by Voyager 2 at Uranus, Puck was the only one detected early enough so that the spacecraft could be instructed to get more detailed images of it.

Very little is known about Puck.

1.175 Neptune - Fast Facts

```
 Physical Characteristics
 ------------------------
 Mass...............................1.024e26 kg  (17.135 times that of Earth)
 Equatorial radius.....................24764 km  (3.8826 times that of Earth)
 Polar radius..........................24341 km  (3.8291 times that of Earth)
 Surface gravity.......................11.14 m/s^2 (1.14 times that of Earth)
 Escape velocity........................23.5 km/s
 Apparent semidiameter at 1 AU..........34.40 arcseconds
 Average density........................1.64 g/cm^3
 Average temperature at 1 atmosphere.....-225 degrees C
 Magnitude at 1 AU.....................-6.87
 Geometric Albedo.......................0.41

 Atmospheric Composition (by number of atoms):
     Hydrogen............................85%
     Helium..............................13%
     Methane..............................2%

 Number of known satellites.................8

                 Proteus    Despina    Thalassa   Triton
                 Larissa    Galatea    Naiad      Nereid


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period, System III...16.1 hours
 Inclination of equator to orbit.........29.56 degrees
 Orbital period (length of year).......163.723 years
 Average orbital velocity...............5.4778 km/sec.
 Eccentricity.....................0.0089880948652
```

```
 Inclination of orbit to ecliptic.....1.769952 degrees
 Distance from Sun:
   Shortest......................4,463,964,000 km (29.83975 AU)
   Average.......................4,504,450,000 km (30.11039 AU)
   Greatest......................4,544,936,000 km (30.38102 AU)
```

1.176 Neptune - Mythology

Neptune was named for the Roman god of the sea. Since sea travel was dangerous in ancient times, sailors prayed to Neptune for safe passage. Neptune is roughly equivalent to the Greek god Poseidon.

Neptune was the son of Saturn and Ops, and the father of Triton. He is usually portrayed as a bearded man carrying a trident, or three-pronged spear.

1.177 Neptune - Discovery

Once Uranus had been discovered by Sir William Herschel, many people measured its orbit. It was soon realized that variations in the orbit suggested the gravitational influence of another, undiscovered planet.

In 1843, John Adams calculated where such a planet would be, and gave his findings to Sir George Airy, the Astronomer Royal of England. Unfortunately, Airy lacked confidence in Adams' work and did not attempt to use a telescope to find the planet.

By 1846, Urbain Leverrier had independently calculated the position of this planet as well (and his results agreed remarkably well with those of Adams). He convinced Johann Galle, the director of the Urania observatory in Berlin, to look for the planet. On September 23, 1846 this planet was found. It became known as Neptune.

A dispute arose between Adams and Leverrier as to who would have the official recognition of having discovered the planet. They are now both credited with Neptune's discovery, even though it is Galle who first observed it.

Despite all of this, it appears that Galileo was actually the first person to have seen Neptune, in January 1613. While observing Jupiter for several nights, Neptune was in the field of view of his telescope. Unfortunately, he didn't realize that Neptune was a new planet, and considered it only a star.

1.178 Neptune - Exploration

Since Neptune is located at such a great distance, telescopes on Earth are generally not large enough to reveal much information about the planet. Only one spacecraft has ever been sent to Neptune - Voyager 2. On August 25, 1989, the spacecraft flew to within a mere 5,000 km of the cloudtops.

Because the light levels at the distance of Neptune and beyond are so low, relatively long exposure times were required by Voyager's camera. Since the spacecraft moved so quickly through the Neptunian system, the images would have been badly blurred if special precautions were not taken. A rotating platform for the camera was not operational, so mission controllers rotated the entire spacecraft throughout an exposure keeping the camera pointed at its target. This had been done successfully at Uranus as well.

1.179 Neptune - Physical Features

Neptune is the smallest of the so-called gas giants (including Jupiter, Saturn, Uranus, and itself). Despite this, almost four planets the size of the Earth could stretch out across its diameter.

Most of our current knowledge about Neptune comes from information returned by the highly successful Voyager 2 spacecraft. There are currently no plans to send another spacecraft to this planet.

View Neptune & Triton, as seen from Voyager 2

Structure of Neptune

Like Uranus, but unlike Jupiter and Saturn which are composed of mostly hydrogen, Neptune only contains about 15% hydrogen and a few percent helium. Most of this is locked up in the planet's thick atmosphere. Beneath this, a more or less homogeneous mixture of ices, rock, and gas is believed to exist. In many ways, Neptune is believed to be similar to the cores of Jupiter and Saturn, without the massive layer of liquid metallic hydrogen surrounding it.

Magnetic field

Like the other gas giants, Neptune was observed to have a magnetic field. However, scientists are at a bit of a loss in explaining how its magnetic field is generated. It was originally assumed that an electrically conducting ocean of water and ammonia lay beneath the atmosphere, providing the mechanisms necessary to generate such a field. However, no such feature was detected by Voyager 2.

Like Uranus, the magnetic field of Neptune does not coincide nicely with the planet's axis of rotation. It is tilted at an angle of 47 degrees, and is offset by at least 13,500 km from the physical center of Neptune. Much work remains to be done before scientists will be able to postulate a plausible mechanism for the generation of this strange field, though it is suspected that it originates from relatively near the surface of the planet. Weak aurorae were seen associated with the magnetic field, though the complexity of the field resulted in their occurrence over large areas. With the Earth and similar terrestrial planets, aurorae are usually confined to the region around the magnetic poles.

Appearance of Neptune

Unlike the disappointment at Uranus, Neptune's atmosphere provided a wealth of detail for scientists. A feature similar to the Great Red Spot on Jupiter was discovered in the southern hemisphere (though only half the size). Dubbed the

"Great Dark Spot" (scientists have never been that creative with names), it was observed to rotate counterclockwise and move westward at a rate of more than 1,100 km/hour.

Another similar, though smaller feature became known as "The Scooter". So called because it travels around the planet at an even higher rate of speed than the Great Dark Spot, its true nature remains a mystery, though it is thought that it may be a plume of gas rising from lower in the atmosphere.

In the following picture, the Great Dark Spot can be seen in the upper left, while The Scooter is visible in the lower right.

View Great Dark Spot & The Scooter

In June 1994, observations by the Hubble Space Telescope indicated that the Great Dark Spot and Scooter had disappeared since the encounter by Voyager 2. However, in April 1995 a new dark spot was observed in the northern hemisphere of the planet. It was nearly a mirror image of the Great Dark Spot.

The winds on Neptune are the fastest observed in the solar system, travelling at speeds of up to 2000 km/hour, in a direction opposite that of the rotation of the planet. As with the other gas giant planets, the winds are more or less confined to bands of latitude.

Neptune appears blue-green in color. This is due to the absorption of red light by methane in the upper atmosphere. Beneath this methane layer, there may be more distinct cloud bands, as had been seen at Jupiter and Saturn.

High altitude clouds, similar to cirrus clouds on Earth, were discovered on Neptune. These clouds were typically observed 50 km above the main clouds on the planet.

View Neptune, as seen from Voyager 2

1.180 Neptune's rings

Like all the gas giant planets, Neptune has rings. From the Earth, only portions of the rings are substantial enough to be observed (the ringlets were detected while observing Neptune occult a star, and seeing the light from the star flicker as the different ring segments blocked its light). As a result, astronomers considered the rings of Neptune to be merely 'arcs' until Voyager 2 revealed them to be complete structures.

The rings of Neptune are very dark, like the rings of Jupiter and Uranus. It is thought that they are composed of fine dust particles placed into orbit about the planet by tiny meteoroids colliding into Neptune's moons.

The rings of Neptune can be summarized by the following table:

Name	Distance (km)	Width (km)
Galle	41,900	15
Leverrier	53,200	15
Lassell	53,200	5,800
Arago	59,000	20

Adams	62,930	<50

NOTE: Distances are measured from the center of the planet.

The Adams ring contained the arcs detected from the Earth. The ring arcs were given the names Liberty, Equality, Fraternity, and Courage. Most of these segments are visible in the following Voyager 2 image of the Adams ring.

View arcs in Adams ring

The forces keeping the arcs from spreading out into a homogeneous ring are not fully understood. It is thought that the gravitational effects of the moon Galatea may play a role.

A closeup of the Fraternity arc in the Adams ring looks like a twisted rope. Most of the apparent structure is caused by the motion of individual ring particles during the 111 second exposure. The image shows that the particles even within the arcs are not evenly spread out. Scientists are still not sure why.

View closeup of Fraternity arc

The following image is a composite of two 591 second exposures, showing the Neptunian ring system from a distance of 280,000 km. Neptune would be located at the center of the black strip running down the picture, but is not visible since the Voyager 2 camera was not directed at the planet (it would have been greatly overexposed). Unfortunately, the arcs of the Adams ring were not in the field of view of either of the pictures, taken 1.5 hours apart.

View ring system of Neptune

1.181 What is the furthest planet from the Sun?

We are often taught the order of the planets from the Sun as:

Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto

But is this always the case?

Pluto’s orbit is quite eccentric. As a result, its distance from the Sun varies wildly - between 4,442,469,000 km and 7,389,129,000 km. Neptune, on the other hand, has a rather circular orbit, with its distance only varying between 4,463,964,000 km and 4,544,936,000 km. Though Pluto is usually located further from the Sun, it is obvious from these numbers that periodically Pluto can actually be nearer to the Sun than Neptune. This is so for 20 years out of the 249 years it takes for Pluto to travel around the Sun.

In fact, this is currently the case. In 1979 Neptune surpassed Pluto and became the furthest planet from the Sun. It will remain this way until 1999, at which time Pluto will regain its traditional role.

1.182 Neptune - Observing the Planet

At its brightest, Neptune reaches a magnitude of just 8.0. This means that it is too dim to be seen by the naked eye, and a small telescope is typically required. "The Digital Universe" can be used to print a star chart of the region around Neptune so that it can be identified.

Under low power, Neptune will look remarkably similar to a bluish-green star. Only with large telescopes and magnifications, under good seeing conditions, will a small disk be apparent. Do not expect to see details on the surface of Neptune - the disk will simply appear much too small for that.

Nevertheless, it is always rewarding to successfully find this elusive planet. Owners of larger telescopes can try and detect the brighter satellites of Neptune - Triton and Nereid. Again, "The Digital Universe" can help you determine where to look.

1.183 Neptune - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience. For images of Neptune's moons, please follow the links to the satellite of interest, provided at the introductory screen for information on the planet.

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Full disk of the planet
The Great Dark Spot and The Scooter
Neptune's rings
Ring arcs in the Adams ring
Closeup of Fraternity arc in Adams ring
Neptune and Triton parting shot
```

1.184 Triton - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...........................Lassell
Date of Discovery.......................1846
Alternate identification...........Neptune I
Mass...............................2.14e22 kg  (3.58e-3 times that of Earth)
Radius..................................1350 km  (0.21167 times that of Earth)
Surface gravity.........................0.78 m/s^2 (0.080 times that of Earth)
Escape velocity........................1.454 km/sec
Apparent semidiameter at 1 AU...........1.88 arcseconds
Average density.........................2.07 g/cm^3
Magnitude at 1 AU......................-1.24
Geometric Albedo.........................0.7

Atmosphere................trace of Nitrogen
                          trace of Methane
Atmospheric pressure at surface.....0.000014 times that of Earth


Orbital Data (for epoch J2000.0)
```

```
 --------------------------------
 Sidereal Rotational period...........-5.8768541 days (*)
 Orbital period.......................-5.8768541 days (*)
 Average orbital velocity...................4.39 km/sec.
 Eccentricity..........................0.000016
 Inclination of orbit to Neptune's equator.157.3 degrees
 Distance from center of Neptune:
   Shortest.........................354,750 km
   Average..........................354,760 km
   Greatest.........................354,770 km
* NOTE:  Triton orbits around Neptune in a retrograde direction. As a result,
its orbital period is given as a negative number of days.  Since it is also in
synchronous rotation, it keeps the same side facing Neptune at all times.
Therefore, it experiences retrograde rotation as well.
```

1.185 Triton - Description

Triton (pronounced TRY-ton) was discovered by Lassell in 1846, just a month after Neptune was discovered. In Greek mythology, Triton is a god of the sea, the son of Poseidon. He is usually portrayed as having the head and torso of a man, and the tail of a fish.

Because Triton orbits and rotates in a retrograde direction, it is not thought to have condensed out of the primordial nebula. It is believed that Triton might have formed elsewhere, and was later captured in the gravitational field of Neptune. However, no credible mechanism has been put forward as to how this might have occurred. A particular problem with the capture theory is the fact that Triton's orbit is quite circular. Most mechanisms by which capture is achieved result in elliptical orbits. In short, scientists are at a bit of a loss to explain how Triton might have originated. Many astronomers think that Triton may have come from the Kuiper Belt.

Due to the fact that Triton's axis of rotation is tilted 157 degrees with respect to Neptune's axis, which is in turn tipped 30 degrees to the plane of Neptune's orbit, the orientation of Triton is such that it appears to be "laying on its side". A similar phenomenon occurs with Uranus, and results in the Sun shining almost directly on one pole, then over the equator, then over the other pole. When Voyager 2 passed by Triton (at a closest approach of 40,000 km), its south pole was in sunlight.

It is thought from analysis of the density of Triton that it is composed of about 25% water ice and 75% rocky material. Triton is one of the few satellites possessing an atmosphere. It is composed primarily of nitrogen with a small amount of methane, and provides a surface pressure 70,000 times weaker than that on the Earth. A thin haze of nitrogen ice particles exists up to 10 km above the surface of the moon. The atmosphere is detectable up to a height of 800 km above Triton's surface.

Because Triton reflects 70% of the feeble light and heat reaching it from the Sun, it is extremely cold. Measurements from Voyager 2 indicate the surface to be a chilly -235 degrees C, only 38 degrees warmer than absolute zero. At this temperature methane, nitrogen, and carbon dioxide are frozen.

There are very few craters visible on the surface of the moon. The northern hemisphere is almost completely covered by an ice cap of frozen nitrogen and methane. A network of ridges and valleys cross the surface of Triton. It is thought that they were caused when the material forming the moon froze solid.

A great surprise to astronomers and scientists was the evidence of geologic activity at this remote place. Similar to geysers, "ice volcanoes" were observed, erupting a combination of liquid nitrogen, methane, and dust. It is thought that they are powered by seasonal heating of the Sun vaporizing these volatile compounds. Voyager 2 observed the plume from one ice volcano rise 8 km above the surface, and extend 140 km "downwind".

In the lower portion of the picture of Triton provided with "The Digital Universe", you can see deposits from several ice volcanoes. They appear as dark streaks on the surface, originating from points below and to the left of them.

Triton is believed to be of the same general size, density, temperature, and chemical composition as Pluto. Since it is likely to be yet some time before Pluto is visited by an interplanetary spacecraft, Triton will remain the best model of Pluto for some time to come.

1.186 Nereid - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...........................Kuiper
Date of Discovery......................1949
Alternate identification..........Neptune II
Mass..............................2.06e19 kg  (3.44e-6 times that of Earth)
Radius..................................170 km  (0.02665 times that of Earth)
Surface gravity.......................0.048 m/s^2 (0.005 times that of Earth)
Escape velocity.......................0.127 km/sec
Apparent semidiameter at 1 AU..........0.24 arcseconds
Average density........................1.00 g/cm^3
Magnitude at 1 AU.......................4.0
Geometric Albedo........................0.4

Atmosphere.............................none


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period.......................360.13619 days
Average orbital velocity..................1.12 km/sec.
Eccentricity............................0.7512
Inclination of orbit to Neptune's equator..29.0 degrees
Distance from center of Neptune:
  Shortest.......................1,371,700 km
  Average........................5,513,400 km
  Greatest.......................9,655,100 km
```

1.187 Nereid - Description

Nereid (pronounced NEER-ee-ed) was discovered by Kuiper in 1949. In Greek mythology, Nereid was a sea nymph.

The orbit of Nereid is the most eccentric of any planet or moon in the solar system. Taking almost a year to travel around Neptune once, its distance varies from 1,371,700 km to 9,655,100 km.

At its nearest, Voyager only came to within 4,700,000 km of Nereid. As such, very little is known about the moon.

1.188 Naiad - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1989
Alternate identification.........Neptune III, 1989 N6
Mass.................................unknown
Radius....................................29 km  (0.00455 times that of Earth)
Surface gravity......................unknown
Escape velocity......................unknown
Apparent semidiameter at 1 AU...........0.04 arcseconds
Average density......................unknown
Magnitude at 1 AU......................10.0
Geometric Albedo.......................0.06

Atmosphere..............................none


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.294396 days
Average orbital velocity..................11.80 km/sec.
Eccentricity............................<0.001
Inclination of orbit to Neptune's equator..4.74 degrees
Distance from center of Neptune:
  Average..........................117,600 km
```

1.189 Naiad - Description

Naiad (pronounced NAY-ed) was discovered by the team of Voyager 2 in 1989. In Greek mythology, Naiad was a nymph who presided over brooks, springs, and fountains.

It is irregularly shaped and shows no sign of geological activity. Naiad is composed of material reflecting only 6% of the Sun's light. It is quite literally as dark as soot.

Very little is known about Naiad.

1.190 Thalassa - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1989
Alternate identification..........Neptune IV, 1989 N5
Mass...............................unknown
Radius..................................40 km  (0.00627 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.06 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................9.1
Geometric Albedo.......................0.06

Atmosphere.............................none


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.311485 days
Average orbital velocity..................11.66 km/sec.
Eccentricity............................<0.001
Inclination of orbit to Neptune's equator..0.21 degrees
Distance from center of Neptune:
  Average...........................73,600 km
```

1.191 Thalassa - Description

Thalassa (pronounced tha-LASS-ah) was discovered by the team of Voyager 2 in 1989. Thalassa is the Greek word for "sea".

Thalassa is irregularly shaped and shows no sign of geological activity. Thalassa is composed of material reflecting only 6% of the Sun's light. It is quite literally as dark as soot. In the picture of Thalassa provided with "The Digital Universe", the satellite appears elongated. This is not its true appearance; the satellite moved while the photograph was being taken, resulting in a smeared image.

Very little is known about Thalassa.

1.192 Despina - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1989
Alternate identification...........Neptune V, 1989 N3
Mass...............................unknown
Radius..................................74 km  (0.01160 times that of Earth)
```

```
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.10 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................7.9
Geometric Albedo........................0.06

Atmosphere..............................none


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period..............unknown
Orbital period........................0.334655 days
Average orbital velocity.................11.47 km/sec.
Eccentricity............................<0.001
Inclination of orbit to Neptune's equator..0.07 degrees
Distance from center of Neptune:
  Average...........................52,600 km
```

1.193 Despina - Description

Despina (pronounced dez-PEE-nah) was discovered by the team of Voyager 2 in 1989. In Greek mythology, Despina was a nymph, the daughter of Poseidon.

Despina is irregularly shaped and shows no sign of geological activity. Despina is composed of material reflecting only 6% of the Sun's light. It is quite literally as dark as soot.

Very little is known about Despina.

1.194 Galatea - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1989
Alternate identification..........Neptune VI, 1989 N4
Mass...............................unknown
Radius..................................79 km  (0.01237 times that of Earth)
Surface gravity.....................unknown
Escape velocity.....................unknown
Apparent semidiameter at 1 AU...........0.11 arcseconds
Average density.....................unknown
Magnitude at 1 AU.......................7.6
Geometric Albedo........................0.06

Atmosphere..............................none


Orbital Data (for epoch J2000.0)
--------------------------------
```

```
Sidereal Rotational period.............unknown
Orbital period.......................0.428745 days
Average orbital velocity.................10.51 km/sec.
Eccentricity...........................<0.001
Inclination of orbit to Neptune's equator..0.05 degrees
Distance from center of Neptune:
  Average..........................62,000 km
```

1.195 Galatea - Description

Galatea (pronounced gal-ah-TEE-ah) was discovered by the team of Voyager 2 in 1989. In Greek mythology, Galatea was a maiden who was originally a statue carved by Pygmalion. Aphrodite brought Galatea to life.

Galatea is irregularly shaped and shows no sign of geological activity. Galatea is composed of material reflecting only 6% of the Sun's light. It is quite literally as dark as soot. In the picture of Galatea provided with "The Digital Universe", the satellite appears elongated. This is not its true appearance; the satellite moved while the photograph was being taken, resulting in a smeared image.

Very little is known about Galatea.

1.196 Larissa - Fast Facts

```
Physical Characteristics
------------------------
Discoverer...................Voyager 2 team
Date of Discovery......................1989
Alternate identification.........Neptune VII, 1989 N2
Mass...............................unknown
Dimensions.........................208x178 km  (0.01631 times that of Earth)
Surface gravity....................unknown
Escape velocity....................unknown
Apparent semidiameter at 1 AU...........0.14 arcseconds
Average density....................unknown
Magnitude at 1 AU.......................7.3
Geometric Albedo.......................0.06

Atmosphere.............................none


Orbital Data (for epoch J2000.0)
--------------------------------
Sidereal Rotational period.............unknown
Orbital period.......................0.554654 days
Average orbital velocity..................9.67 km/sec.
Eccentricity...........................<0.001
Inclination of orbit to Neptune's equator..0.20 degrees
Distance from center of Neptune:
  Average..........................50,000 km
```

1.197 Larissa - Description

Larissa (pronounced LA-ree-sah) was discovered by the team of Voyager 2 in 1989. In Greek mythology, Larissa was the mother of Poseidon.

Although the Voyager team is credited with the "official" discovery of Larissa, Dave Tholen appears to have detected the moon in 1981 by stellar occultation observations.

Larissa is irregularly shaped and appears to be heavily cratered. Larissa is composed of material reflecting only 6% of the Sun's light. It is quite literally as dark as soot.

Very little is known about Larissa.

1.198 Proteus - Fast Facts

```
 Physical Characteristics
 ------------------------
 Discoverer...................Voyager 2 team
 Date of Discovery......................1989
 Alternate identification........Neptune VIII, 1989 N1
 Mass...............................unknown
 Dimensions......................436x416x402 km  (0.03136 times that of Earth)
 Surface gravity.....................unknown
 Escape velocity.....................unknown
 Apparent semidiameter at 1 AU...........0.28 arcseconds
 Average density.....................unknown
 Magnitude at 1 AU.......................5.6
 Geometric Albedo.......................0.06

 Atmosphere.............................none


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period..............unknown
 Orbital period........................1.122315 days
 Average orbital velocity..................7.63 km/sec.
 Eccentricity............................<0.001
 Inclination of orbit to Neptune's equator..0.55 degrees
 Distance from center of Neptune:
   Average...........................48,200 km
```

1.199 Proteus - Description

Proteus (pronounced PROH-tee-us) was discovered by the team of Voyager 2 in 1989. In Greek mythology, Proteus was a sea god who could change his shape at will.

Proteus is heavily cratered and irregularly shaped. Scientists believe that Proteus is about as big as an irregularly shaped object can be. If it were much more massive, the higher gravitational field would tend to smooth out the surface into a more spherical shape. Proteus is composed of material reflecting only 6% of the Sun’s light. It is quite literally as dark as soot.

Very little is known about Proteus.

1.200 Pluto - Fast Facts

```
 Physical Characteristics
 ------------------------
 Mass...............................1.29e22 kg  (0.0022 times that of Earth)
 Equatorial radius.....................1151 km  (0.1805 times that of Earth)
 Polar radius..........................1151 km  (0.1811 times that of Earth)
 Surface gravity.......................0.65 m/s^2 (0.07 times that of Earth)
 Escape velocity.......................1.22 km/s
 Apparent semidiameter at 1 AU..........1.60 arcseconds
 Average density.......................2.05 g/cm^3
 Average temperature...................-215 degrees C
 Magnitude at 1 AU.....................-1.0
 Geometric Albedo.......................0.3

 Atmospheric Composition (by number of atoms):
     Nitrogen.......................unknown
     Carbon Monoxide.................unknown

 Number of known satellites................1

                 Charon


 Orbital Data (for epoch J2000.0)
 --------------------------------
 Sidereal Rotational period............6.38725 days
 Inclination of equator to orbit...........122 degrees (*)
 Orbital period (length of year).......248.021 years
 Average orbital velocity................4.749 km/sec.
 Eccentricity.........................0.249050
 Inclination of orbit to ecliptic....17.142167 degrees
 Distance from Sun:
   Shortest.....................4,442,469,000 km (29.69607 AU)
   Average......................5,915,799,000 km (39.54467 AU)
   Greatest.....................7,389,129,000 km (49.39327 AU)
* NOTE: Since Pluto experiences retrograde rotation, the inclination of the
equator to its orbit is given as an angle greater than 90 degrees.
```

1.201 Pluto - Mythology

Pluto was named after the Roman god of the dead and the underworld. He is roughly equivalent to the Greek god Hades.

After Pluto had been discovered, many suggestions came in for its name. It is believed that the name "Pluto" was chosen because the planet is so far from the

Sun that very little light ever reaches it.

1.202 Pluto - Discovery

Pluto was actually discovered by accident. Astronomers had noted that the motions of Uranus and Neptune did not agree completely with that predicted by the laws of physics. They realized that these deviations could be explained if the gravity of an undiscovered planet affected their orbits. They calculated where such an object would be, and a young astronomer named Clyde Tombaugh carried out a survey of the sky in the region. After years of painstaking work, he discovered the planet Pluto on February 18, 1830.

The following picture contains the two images that Tombaugh used to make his discovery. The planet is denoted by the orange crosshairs, and its motion across the background stars is plainly evident.

View discovery photographs of Pluto

The accident in the discovery of Pluto was that the mathematicians who calculated its predicted position had made an error. Pluto was too small, and in the wrong place to cause the observed deviations in the orbits of Uranus and Neptune. The search for the missing Planet X continued. This hypothetical planet has never been found, and based on more accurate data for the masses of Uranus and Neptune provided by Voyager 2, most astronomers no longer believe that a large undiscovered object still exists.

1.203 Pluto - Exploration

Pluto is the only planet in our solar system which has not been visited by a spacecraft. So far, all our knowledge about the planet has been based on observations from telescopes on Earth or in orbit around Earth.

A tentative schedule exists for future exploration of Pluto by a spacecraft. If approved, the Pluto Fast Flyby mission will launch in 2000 or 2001, arriving at the planet between 2007-2010.

1.204 Pluto - Physical Features

Pluto is the smallest planet in our solar system. In fact, it is smaller than seven of the solar system’s moons - The Earth’s moon, Io, Europa, Ganymede, Callisto, Titan, and Triton. Due to this small size, its great distance, and the fact that no spacecraft have yet gone to visit it, very little is known about the planet. Even the Hubble Space Telescope is unable to resolve any but the most rudimentary features on its surface.

However, Pluto’s moon Charon was discovered in 1978. By good fortune, this was just before its orbit became edge-on as viewed from the Earth. From our point of view, the moon periodically appeared to move directly behind, and in front of Pluto. Through careful calculations of the position of the moon, and precise measurements of how the magnitude of Pluto and Charon fluctuated

```
throughout these occultations, scientists were able to use high speed computers
to construct a rough map of the light and dark areas of both bodies.  The
series of occultations only lasted a few years - if we had missed our chance,
we would have to wait 120 years for another.

Because Pluto is such a small object, many people feel that it would be better
classified as a large asteroid or comet instead of a planet. Since there is no
scientific definition as to how large an object must be to be considered a
planet, the discussion is open to debate.  Many astronomers feel that Pluto may
have originated from within the Kuiper Belt.

Pluto is so far away that the Sun would merely appear as a very bright star in
its sky.

 Composition of Pluto
 --------------------
 The composition of Pluto is largely unknown.  Its density suggests that it is
likely similar to Triton, being composed of 80% rock, and 20% ices (of water,
methane, nitrogen, carbon dioxide, and carbon monoxide).


 Atmosphere of Pluto
 -------------------
 Studies from Earth-based telescopes have yielded evidence to suggest that
Pluto's atmosphere is composed of carbon monoxide and nitrogen.  However, these
compounds exist in gaseous state only when Pluto is near perihelion.  For the
majority of Pluto's year, the temperature is too cold, and the atmosphere lies
frozen on the surface of the planet.  Organizers for the Pluto Fast Flyby
mission therefore want to launch the spacecraft as soon as possible so that it
arrives at the planet while the atmosphere is still unfrozen.


 Rotation of Pluto
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 Pluto rotates around its axis once every 6.38725 days.  This happens to be the
same amount of time that it takes its moon Charon to revolve around the planet.
As a result, Pluto always keeps the same side facing its moon, and it is said
to be in synchronous rotation.

Charon also rotates around its axis in 6.38725 days.  As a result, it too keeps
the same side facing Pluto.  Pluto and Charon are the only pair of objects in
the solar system known to experience mutual synchronous rotation like this.
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1.205 Pluto - its strange orbit

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Pluto has the most unique orbit of any other planet in our solar system.  It is
different in two fundamental respects:

 1.  It has the most eccentric orbit of any planet.
     See What is the furthest planet from the Sun? for details.

 2.  The inclination of its orbit to the ecliptic is higher than
     that of any other planet.  This means that while most planets
     in the solar system orbit in more or less the same plane, the
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plane of Pluto's orbit is "tipped" by more than 17 degrees.

1.206 Pluto - Observing the Planet

At its brightest, Pluto remains dimmer than magnitude 13. Therefore, a large telescope is required to see it.

At best, Pluto will appear as a dim, inconspicuous point of light, easy to confuse as a star. To identify the planet, it is best to observe the region over several days, sketching the appearance of the field. Pluto will be the object that moves against the background of stars.

Since Pluto's moon Charon was not discovered until 1978, and is only visible through the largest telescopes, it is unlikely that an amateur will have access to the equipment necessary to detect it. Its position is provided with "The Digital Universe" for interest's sake.

1.207 Pluto - Pictures

Though links to these pictures occur in various places throughout the document, they are provided here as well for convenience.

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Discovery photographs of Pluto
Pluto & Charon, from ground-based and Hubble observations
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1.208 Charon - Fast Facts

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Physical Characteristics
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Discoverer.......................J. Christy
Date of Discovery......................1978
Alternate identification............Pluto I
Mass...............................1.08e21 kg  (2.96e-4 times that of Earth)
Radius.................................635 km  (0.09956 times that of Earth)
Surface gravity......................0.293 m/s^2 (0.030 times that of Earth)
Escape velocity......................0.431 km/sec
Apparent semidiameter at 1 AU...........0.88 arcseconds
Average density.........................1.3 g/cm^3
Magnitude at 1 AU.......................0.9
Geometric Albedo........................0.5

Atmosphere..............................none


Orbital Data (for epoch J2000.0)
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Sidereal Rotational period..............6.38725 days
Orbital period..........................6.38725 days
Average orbital velocity...................0.23 km/sec.
Eccentricity............................<0.001
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 Inclination of orbit to Pluto's equator....98.8 degrees
 Distance from center of Pluto:
   Average............................19,460 km
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1.209 Charon - Description

Charon (pronounced SHAR-on) was discovered by J. Christy on June 22, 1978. Photographs taken during April and May 1978 showed a somewhat elongated image of Pluto. The slight bulge in the side of the planet turned out to be a moon, orbiting quite near the surface.

In Greek mythology, Charon was a boatman who ferried the souls of the dead across the River Styx to Hades. He demanded a bronze coin called an "obolus" in payment for these services. In a proper Greek burial, such a coin was placed under the tongue of the deceased, as souls without payment were forced to wander on the shore for years before being ferried across. Charon is usually depicted as an ugly old man with a tangled beard, and wearing a dirty robe.

Charon is unique in that it is the largest moon with respect to the planet it orbits. As a result, some people consider Pluto and Charon to be a "double planet". Additionally, Charon and Pluto both rotate synchronously, keeping the same sides facing each other at all times. It is the only known example in the solar system where both the moon and parent body are in synchronous rotation.

Since Charon is so small, so far away, and as yet unvisited by spacecraft, we know very little about the moon. Our only information about surface features was obtained during the end of the 1980s when Pluto and Charon experienced a series of mutual occultations. By measuring how the magnitude of the system varied as the two bodies moved in front of each other, scientists were able to use powerful computers to construct crude maps of the surface of both Pluto and Charon.

The low density of Charon suggests that it is made of a combination of water ice and rock. Its surface seems to be covered with a layer of water ice. There is evidence to suggest that a thin atmosphere may exist on Charon, but astronomers need more data to be able to tell for certain.

Some astronomers think that Charon, like Pluto, may have originated from the Kuiper Belt.