
Be A
Stargazer
A Guide To Astronomy

PREFACE

All sciences are making an advance, but Astronomy is moving at high speed. Since the principles of this science were settled by Copernicus, four hundred years ago, it has never had to beat a retreat. It is rewritten not to correct material errors, but to incorporate new discoveries.

At one time, Astronomy studied mostly tides, seasons, and telescopic aspects of the planets; now these are only primary matters. Once it considered stars as mere fixed points of light; now it studies them as suns, determines their age, size, color, movements, chemical constitution, and the revolution of their planets. Once it considered space as empty; now it knows that every cubic inch of it quivers with greater intensity of force than that which is visible in Niagara. Every inch of surface that can be conceived of between suns is more wave-tossed than the ocean in a storm.

The invention of the telescope constituted one era in Astronomy; its perfection in our day, another; and the discoveries of the spectroscope a third—no less important than either of the others. New discoveries are made every day with the advancement of telescopes. The Hubble space telescope has let man see further into the universe then ever before. Astronomy and space science is an ever changing study, and possibly the most exciting of the sciences. It is for one reason that this book was written, to hopefully interest more people in the exciting study of the universe around us.

CONTENTS

Why Study Light?

For most of history, humans have used visible light to explore the skies. With basic tools and the human eye, we developed sophisticated methods of time keeping and calendars. Telescopes were invented in the 17th century. Astronomers then mapped the sky in greater detail––still with visible light. They learned about the temperature, constituents, distribution, and the motions of stars.

There are two main techniques for analyzing starlight. One is called spectroscopy and the other photometry. Spectroscopy spreads out the different wavelengths of light into a spectrum for study. Photometry measures the quantity of light in specific wavelengths or by combining all wavelengths. Astronomers use many filters in their work. Filters help astronomers analyze particular components of the spectrum. For example, a red filter blocks out all visible light wavelengths except those that fall around 600 nanometers (it lets through red light).

Introduction to Light

Light is a form of radiant energy or energy that travels in waves. Since Greek times, scientists have debated the nature of light. Physicists now recognize that light sometimes behaves like waves and, at other times, like particles. When moving from place to place, light acts like a system of waves. In empty space, light has a fixed speed and the wavelength can be measured. In the past 300 years, scientists have improved the way they measure the speed of light, and they have determined that it travels at nearly 299,792 kilometers, or 186,281 miles, per second.

When we talk about light, we usually mean any radiation that we can see. These wavelengths range from about 16/1,000,000 of an inch to 32/1,000,000 of an inch. There are other kinds of radiation such as ultraviolet light and infrared light, but their wavelengths are shorter or longer than the visible light wavelengths. When light hits some form of matter, it behaves in different ways. When it strikes an opaque object, it makes a shadow, but light does bend around obstacles. The bending of light around edges or around small slits is called diffraction and makes patterns of bands or fringes.

All light can be traced to certain energy sources, like the Sun, an electric bulb, or a match, but most of what hits the eye is reflected light. When light strikes some materials, it is bounced off or reflected. If the material is not opaque, the light goes through it at a slower speed, and it is bent or refracted. Some light is absorbed into the material and changed into other forms of energy, usually heat energy. The light waves make the electrons in the materials vibrate and this kinetic energy or movement energy makes heat. Friction of the moving electrons makes heat.

Experiments With Light

A light set in a room is seen from every place; hence light streams in every possible direction. If put in the centre of a hollow sphere, every point of the surface will be equally illumined. If put in a sphere of twice the diameter, the same light will fall on all the larger surface. The surfaces of spheres are as the squares of their diameters; hence, in the larger sphere the surface is illumined only one-quarter as much as the smaller. The same is true of large and small rooms. In Fig. 7 it is apparent that the light that falls on the first square is spread, at twice the distance, over the second square, which is four times as large, and at three times the distance over nine times the surface. The varying amount of light received by each planet is also shown in fractions above each world, the amount received by the earth being 1.

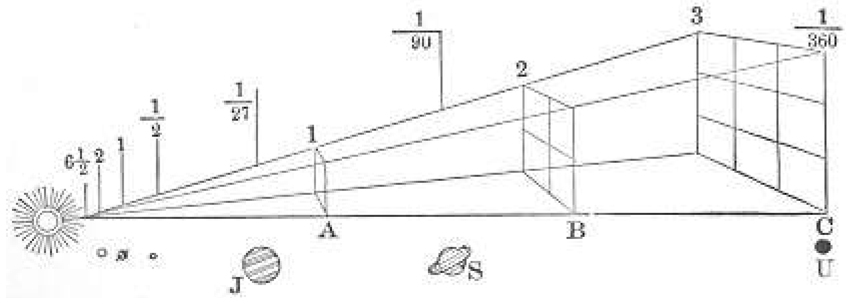


Fig. 7.

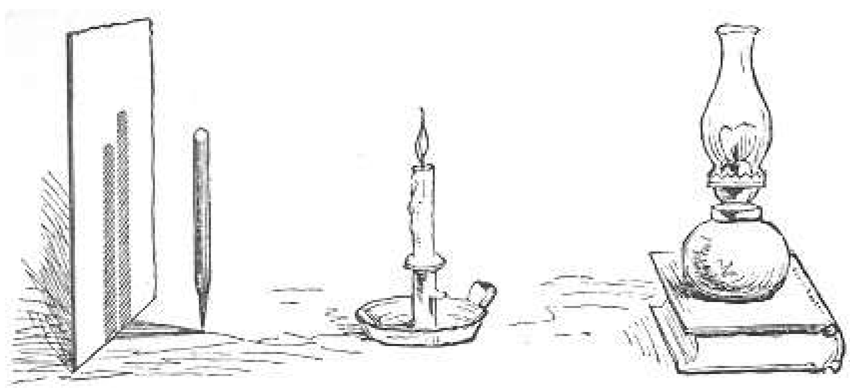


Fig. 8.—Measuring Intensities of Light.

The intensity of light is easily measured. Let two lights of different brightness, as in Fig. 8, cast shadows on the same screen. Arrange them as to distance so that both shadows shall be equally dark. Let them fall side by side, and study them carefully. Measure the respective distances. Suppose one is twenty inches, the other forty. Light varies as the square of the distance: the square of 20 is 400, of 40 is 1600. Divide 1600 by 400, and the result is that one light is four times as bright as the other.

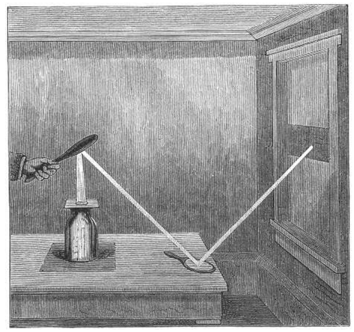


Fig. 9.—Reflection and Diffusion of Light.

Light can be handled, directed, and bent, as well as iron bars. Darken a room and admit a beam of sunlight through a shutter, or a ray of lamp-light through the key-hole. If there is dust in the room it will be observed that light goes in straight lines. Because of this men are able to arrange houses and trees in rows, the hunter aims his rifle correctly, and the astronomer projects straight lines to infinity. Take a hand-mirror, or better, a piece of glass coated on one side with black varnish, and you can send your ray anywhere. By using two mirrors, or having an assistant and using several, you can cause a ray of light to turn as many corners as you please.

Set a small light near one edge of a mirror; then, by putting the eye near the opposite edge, you see almost as many flames as you please from the multiplied reflections. How can this be accounted for?

Into your beam of sunlight, admitted through a half-inch hole, put the mirror at an oblique angle; you can arrange it so as to throw half a dozen bright spots on the opposite wall.

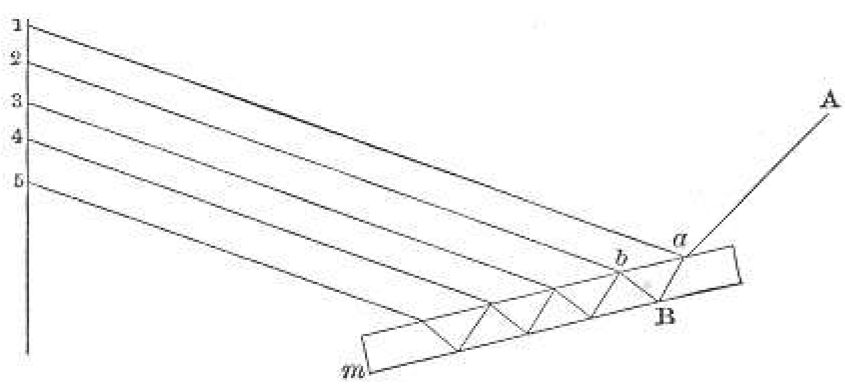


Fig. 10.—Manifold Reflections.

In Fig. 10 the sunbeam enters at A, and, striking the mirror m at a, is partly reflected to 1 on the wall, and partly enters the glass, passes through to the silvered back at B, and is totally reflected to b, where it again divides, some of it going to the wall at 2, and the rest, continuing to make the same reflections and divisions, causes spots 3, 4, 5, etc. The brightest spot is at No.2, because the silvered glass at B is the best reflector and has the most light.

Take a small piece of mirror, say an inch in surface, and putting under it three little pellets of wax, putty, or clay, set it on the wrist, with one of the pellets on the pulse. Hold the mirror steadily in the beam of light, and the frequency and prominence of each pulse-beat will be indicated by the tossing spot of light on the wall. If the operator becomes excited the fact will be evident to all observers.

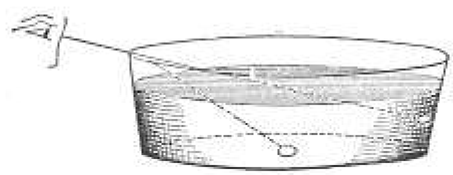


Fig. 11.

Place a coin in a basin (Fig. 11), and set it so that the rim will conceal the coin from the eye. Pour in water, and the coin will appear Page 40 to rise into sight. When light passes from a medium of one density to a medium of another, its direction is changed. Thus a stick in water seems bent. Ships below the horizon are sometimes seen above, because of the different density of the layers of air.

Thus light coming from the interstellar spaces, and entering our atmosphere, is bent down more and more by its increasing density. The effect is greatest when the sun or star is near the horizon, none at all in the zenith. This brings the object into view before it is risen. Allowance for this displacement is made in all delicate astronomical observations.

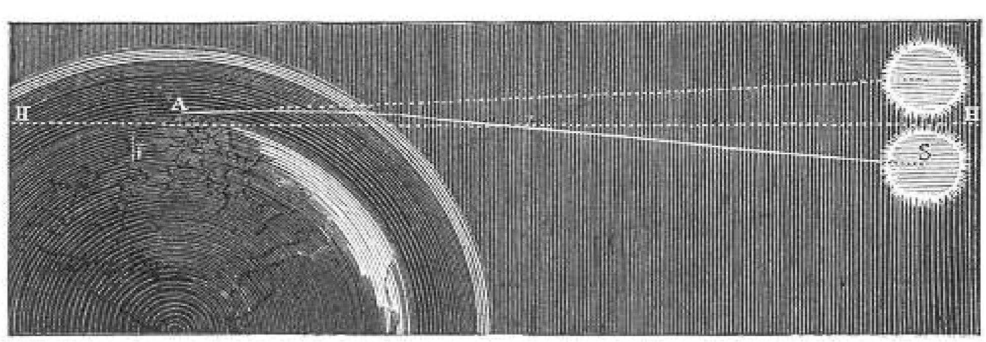


Fig. 12.—Atmospherical Refraction.

Notice on the floor the shadow of the window-frames. The glass of almost every window is so bent as to turn the sunlight aside enough to obliterate some of the shadows or increase their thickness.

DECOMPOSITION OF LIGHT

Admit the sunbeam through a slit one inch long and one-twentieth of an inch wide. Pass it through a prism. Either purchase one or make it of three plain pieces of glass one and a half inch wide by six inches long, fastened together in triangular shape—fasten the edges with hot wax and fill it with water; then on a screen or wall you will have the colors of the rainbow, not merely seven but seventy, if your eyes are sharp enough.

Take a bit of red paper that matches the red color of the spectrum. Move it along the line of colors toward the violet. In the orange it is dark, in the yellow darker, in the green and all beyond, black. That is because there are no more red rays to be reflected by it. So a green object is true to its color only in the green rays, and black elsewhere. All these colors may be recombined by a second prism into white light

Introduction to Color

Color is a part of the electromagnetic spectrum and has always existed, but the first explanation of color was provided by Sir Isaac Newton in 1666. Newton passed a narrow beam of sunlight through a prism located in a dark room. Of course all the visible spectrum (red, orange, yellow, green, blue, indigo, and violet) was displayed on the white screen. People already knew that light passed through a prism would show a rainbow or visible spectrum, but Newton's experiments showed that different colors are bent through different angles. Newton also thought all colors can be found in white light, so he passed the light through a second prism. All the visible colors changed back to white light. Light is the only source of color.

The color of an object is seen because the object merely reflects, absorbs, and transmits one or more colors that make up light. The endless variety of color is caused by the interrelationship of three elements: Light, the source of color; the material and its response to color; and the eye, the perceiver of color. Colors made by combining blue, yellow, and red light are called additive; and they are formed by adding varying degrees of intensity and amounts of these three colors. These primary colors of light are called cyan (blue-green), yellow, and magenta (blue-red).

Pigment color found in paint, dyes, or ink is formed by pigment molecules present in flowers, trees, and animals. The color is made by absorbing, or subtracting, certain parts of the spectrum and reflecting or transmitting the parts that remain. Each pigment molecule seems to have its own distinct characteristic way of reflecting, absorbing, or transmitting certain wavelengths. Natural and manmade colors all follow the same natural laws.

Building A Simple Spectroscope

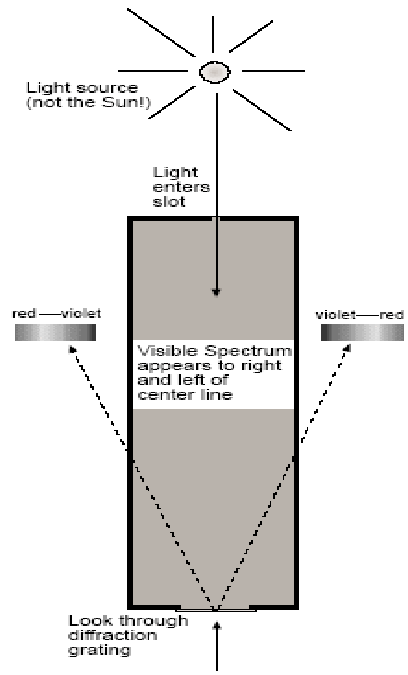
A basic hand-held spectroscope can be made from a diffraction grating and a paper tube.

Objective:

To construct a simple spectroscope with a diffraction grating and use it to analyze the colors emitted by various light sources.

Materials:

Diffraction grating, 2-cm square
Paper tube (tube from toilet paper roll)
Poster board square (5 by 10-cm)
Masking tape
Scissors
Razor blade knife
2 single-edge razor blades
Pencil



Procedure:

1. Using the pencil, trace around the end of the paper tube on the poster board. Make two circles and cut them out. The circles should be just larger than the tube's opening.

2.Cut a 2-centimeter square hole in the center of one circle. Tape the diffraction grating square over the hole.

3. Tape the circle with the grating inward to one end of the tube.

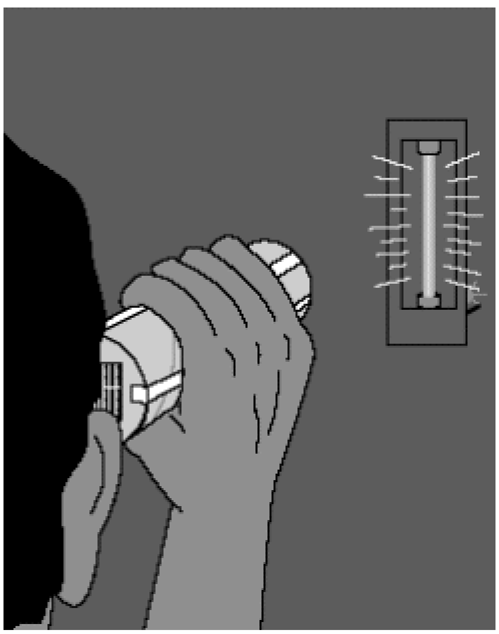
4. Make a slot cutter tool by taping two single- edge razor blades together with a piece of poster board between. Use the tool to make parallel cuts about 2 centimeters long across the middle of the second circle. Use the razor blade knife to cut across the ends of the

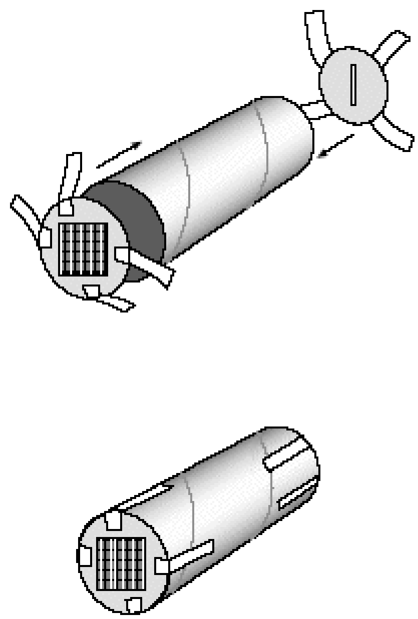
cuts to form a narrow slot across the middle of the circle.

5. Place the circle with the slot against the other end of the tube. While holding it in place, observe a light source such as a fluorescent tube. Be sure to look through the grating end of the spectroscope. The spectrum will appear off to the side from the slot. Rotate the circle with the slot until the spectrum is as wide as possible. Tape the circle to the end of the tube in this position. The spectroscope is complete.

6. Examine various light sources with the spectroscope.
If possible, examine nighttime street lighting. Use particular caution when examining sunlight. Do not look directly into the Sun.

Background:





Simple spectroscopes, like the one described here, are easy to make and offer users a quick look at the color components of visible light. Different light sources (incandescent, fluorescent, etc.) may look the same to the naked eye but will appear differently in the spectroscope. The colors are arranged in the same order but some may be missing and their intensity will vary. The appearance of the spectrum displayed is distinctive and can tell the observer what the light source is.

A diffraction grating can spread out the spectrum more than a prism can. This ability is called dispersion. Because gratings are smaller and lighter, they are well suited for spacecraft where size and weight are important considerations. Most research telescopes have some kind of grating spectrograph attached. Spectrographs are spectroscopes that provide a record, photographic or digital, of the spectrum observed.

Many school science supply houses sell diffraction grating material in sheets or rolls. When using the spectroscope to observe sunlight, students should look at reflected sunlight such as light bouncing off clouds or light colored concrete. Other light sources include streetlights (mercury, low-pressure sodium, and high-pressure sodium), neon signs, and candle flames.

ASTRONOMICAL INSTRUMENTS

THE TELESCOPE

Some astronomical instruments are of the simplest character, some most delicate and complex. When a man smokes a piece of glass, in order to see an eclipse of the sun, he makes a simple instrument. Ferguson, lying on his back and slipping beads on a string at a certain distance above his eye, measured the relative distances of the stars.

Refracting Telescope

The use of more complex instruments commenced when Galileo applied the telescope to the heavens. He cannot be said to have invented the telescope, but he certainly constructed his own without a pattern, and used it to good purpose. It consists of a lens, O B (Fig. 13), which acts as a multiple prism to bend all the rays to one point at R. Place the eye there, and it receives as much light as if it were as large as the lens O B. The rays, however, are convergent, and the point difficult to find. Hence there is placed at R a concave lens, passing through which the rays emerge in parallel lines, and are received by the eye. Binoculars are made upon precisely this principle today, because they can be made conveniently short.

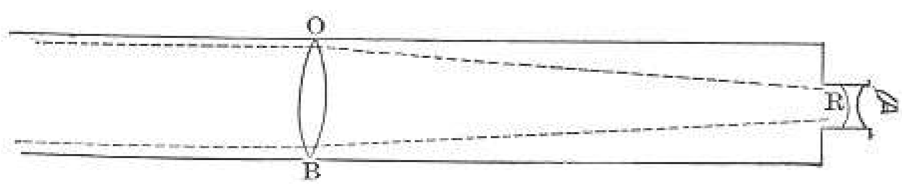


Fig. 13.—Refracting Telescope.

If, instead of a concave lens at R, converting the converging rays into parallel ones, we place a convex or magnifying lens, the minute image is enlarged as much as an object seems diminished when the telescope is reversed. This is the grand principle of the refracting telescope. Difficulties innumerable arise as we attempt to enlarge the instruments. These have been overcome, one after another.

The Reflecting Telescope

This instrument differs radically from the refracting one already described. It receives the light in a concave mirror, M (Fig. 14), which reflects it to the focus F, producing the same result as the lens of the refracting telescope. Here a mirror may be placed obliquely, reflecting the image at right angles to the eye, outside the tube, in which case it is called the Newtonian telescope; or a mirror at R may be placed perpendicularly, and send the rays through an opening in the mirror at M. This form is called the Gregorian telescope. Or the mirror M may be slightly inclined to the coming rays, so as to bring the point F entirely outside the tube, in which case it is called the Herschelian telescope. In either case the image may be magnified, as in the refracting telescope.

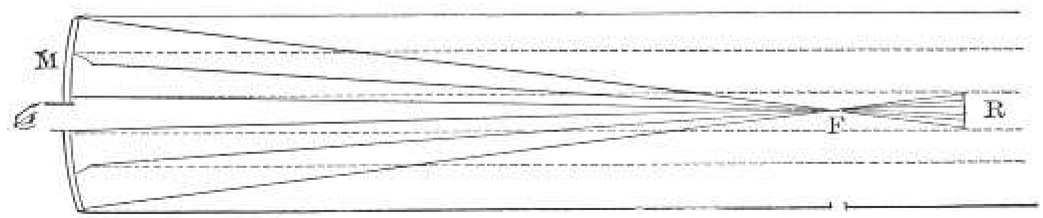


Fig. 14.—Reflecting Telescope.

Reflecting telescopes are made of all sizes, up to the Cyclopean eye of the Subaru telescope which is 327 inches i diameter. The form of instrument to be preferred depends on the use to which it is to be put. The loss of light in passing through glass lenses is about two-tenths. The loss by reflection is often one-half. In view of this peculiarity and many others, it is held that a twenty-six-inch refractor is fully equal to any six-foot reflector.

The mounting of large telescopes demands the highest engineering ability. The whole instrument, with its vast weight , with its accompanying tube and appurtenances, must be pointed as accuratley as a rifle, and held as steadily as the axis of the globe. To give it the required steadiness, the foundation on which it is placed is sunk deep in the earth, far from rail or other roads, and no part of the observatory is allowed to touch this support.

When a star is once found, the earth swiftly rotates the telescope away from it, and it passes out of the field. To avoid this, clock-work is so arranged that the great telescope follows the star by the hour, if required. It will take a star at its eastern rising, and hold it constantly in view while it climbs to the meridian and sinks in the west. The reflector demands still more difficult engineering.

The Spectroscope

A spectrum is a collection of the colors which are dispersed by a prism from any given light. If it is sunlight, it is a solar spectrum; if the source of light is a star, candle, glowing metal, or gas, it is the spectrum of a star, candle, glowing metal, or gas. An instrument to see these spectra is called a spectroscope.

Considering the infinite variety of light, and its easy modification and absorption, we should expect an immense number of spectra. A mere prism disperses the light so imperfectly that different orders of vibrations, perceived as colors, are mingled. No eye can tell where one commences or ends. Such a spectrum is said to be impure. What we want is that each point in the spectrum should be made of rays of the same number of vibrations. As we can let only a small beam of light pass through the prism, in studying celestial objects with a telescope and spectroscope we must, in every instance , contract the aperture of the instrument until we get only a small beam of light.

In order to have the colors thoroughly dispersed, the best instruments pass the beam of light through a series of prisms called a battery, each one spreading farther the colors which the previous ones had spread.

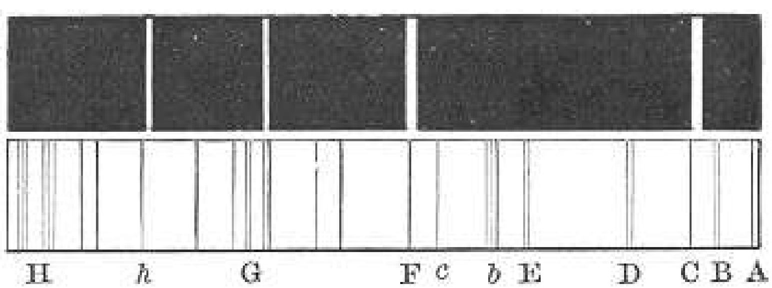
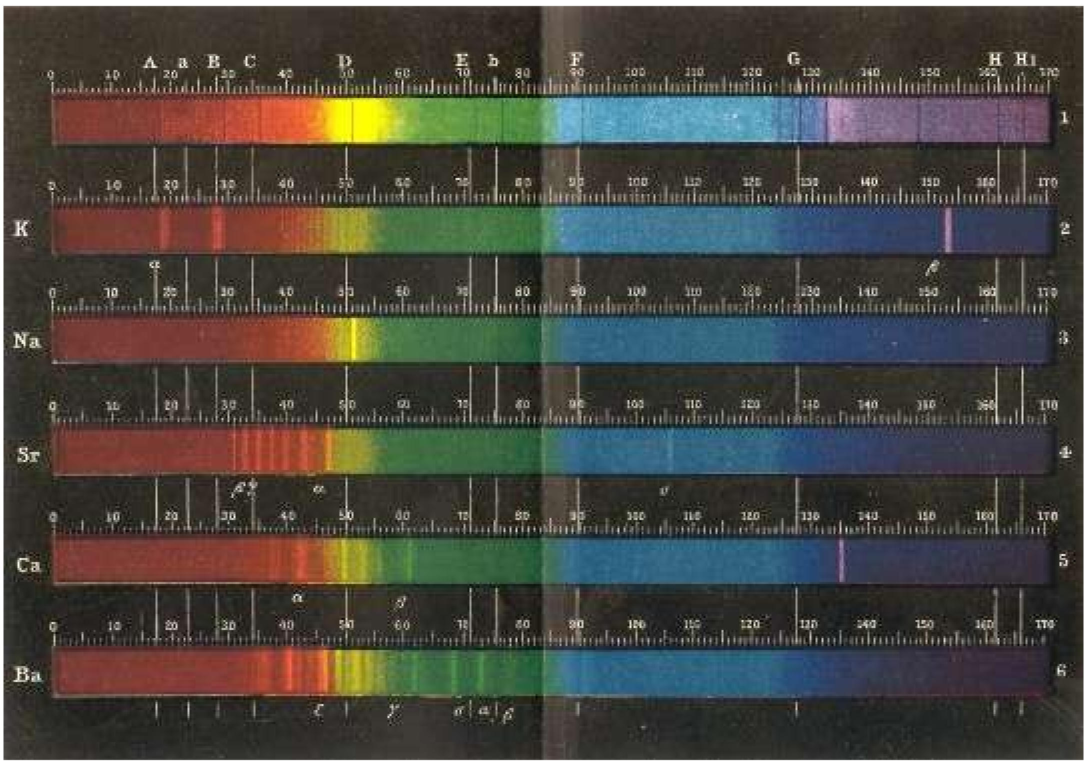


Fig. 18.—Spectra of glowing Hydrogen and the Sun.

In Fig. 18 is seen, in the lower part, a spectrum of the sun, with about a score of its thousands of lines made evident. In the upper part is seen the spectrum of bright lines given by glowing hydrogen gas. These lines are given by no other known gas; they are its autograph. It is readily observed that they precisely correspond with certain dark lines in the solar spectrum. Hence we easily know that a glowing gas gives the same bright lines that it absorbs from the light of another source passing through it—that is, glowing gas gives out the same rays of light that it absorbs when it is not glowing.

The subject becomes clearer by a study of the chromolithic plate. No. 1 represents the solar spectrum, with a few of its lines on an accurately graduated scale. No.3 shows the bright line of glowing sodium, and, corresponding to a dark line in the solar spectrum, shows the presence of salt in that body. No. 2 shows that potassium has some violet rays, but not all; and there being no dark line to correspond in the solar spectrum, we infer its absence from the sun. No.6 shows the numerous lines and bands of barium—several red, orange, yellow, and four are very bright green ones. The lines given by any volatilized substances are always in the same place on the scale.



Our Solar System

From our small world we have gazed upon the cosmic ocean for thousands of years. Ancient astronomers observed points of light that appeared to move among the stars. They called these objects planets, meaning wanderers, and named them after Roman deities - Jupiter, king of the gods; Mars, the god of war; Mercury, messenger of the gods; Venus, the god of love and beauty, and Saturn, father of Jupiter and god of agriculture. The stargazers also observed comets with sparkling tails, and meteors or shooting stars apparently falling from the sky.

Since the invention of the telescope, three more planets have been discovered in our solar system: Uranus (1781), Neptune (1846), and Pluto (1930). In addition, there are thousands of small bodies such as asteroids and comets. Most of the asteroids orbit in a region between the orbits of Mars and Jupiter, while the home of comets lies far beyond the orbit of Pluto, in the Oort Cloud.

The four planets closest to the Sun - Mercury, Venus, Earth, and Mars - are called the terrestrial planets because they have solid rocky surfaces. The four large planets beyond the orbit of Mars - Jupiter, Saturn, Uranus, and Neptune - are called gas giants. Tiny, distant, Pluto has a solid but icier surface than the terrestrial planets.

Nearly every planet - and some of the moons - has an atmosphere. Earth's atmosphere is primarily nitrogen and oxygen. Venus has a thick atmosphere of carbon dioxide, with traces of poisonous gases such as sulfur dioxide. Mars' carbon dioxide atmosphere is extremely thin. Jupiter, Saturn, Uranus, and Neptune are primarily hydrogen and helium. When Pluto is near the Sun, it has a thin atmosphere, but when Pluto travels to the outer regions of its orbit, the atmosphere freezes and collapses to the planet's surface. In that way, Pluto acts like a comet.

There are 141 known natural satellites (also called moons) in orbit around the various planets in our solar system, ranging from bodies larger than our own Moon to small pieces of debris. Many of these were discovered by planetary spacecraft. Some of these have moons have atmospheres (Saturn's Titan); some even have magnetic fields (Jupiter's Ganymede). Jupiter's moon Io is the most volcanically active body in the solar system. An ocean may lie beneath the frozen crust of Jupiter's moon Europa, while images of Jupiter's moon Ganymede show historical motion of icy crustal plates. Some planetary moons may actually be asteroids that were captured by a planet's gravity. The captured asteroids presently counted as moons may include Phobos and Deimos, several satellites of Jupiter, Saturn's Phoebe, many of Uranus' new satellites, and possibly Neptune's Nereid.

From 1610 to 1977, Saturn was thought to be the only planet with rings. We now know that Jupiter, Uranus, and Neptune also have ring systems, although Saturn's is by far the largest. Particles in these ring systems range in size from dust to boulders to house sized, and may be rocky and/or icy.

Most of the planets also have magnetic fields which extend into space and form a magnetosphere around each planet. These magnetospheres rotate with the planet, sweeping charged particles with them. The Sun has a magnetic field, the heliosphere, which envelops our entire solar system.

Ancient astronomers believed that the Earth was the center of the Universe, and that the Sun and all the other stars revolved around the Earth. Copernicus proved that Earth and the other planets in our solar system orbit our Sun. Little by little, we are charting the Universe, and an obvious question arises: Are there other planets where life might exist? Only recently have astronomers had the tools to indirectly detect large planets around other stars in nearby solar systems.

The Sun

Our Sun has inspired mythology in almost all cultures, including ancient Egyptians, Aztecs, Native Americans, and Chinese. We now know that the Sun is a huge, bright sphere of mostly ionized gas, about 4.5 billion years old, and is the closest star to Earth at a distance of about 150 million km. The next closest star - Proxima Centauri - is nearly 268,000 times farther away. There are millions of similar stars in the Milky Way Galaxy (and billions of galaxies in the universe). Our Sun supports life on Earth. It powers photosynthesis in green plants and is ultimately the source of all food and fossil fuel. The connection and interaction between the Sun and the Earth drive the seasons, currents in the ocean, weather, and climate.

The Sun is some 333,400 times more massive than Earth and contains 99.86 percent of the mass of the entire solar system. It is held together by gravitational attraction, producing immense pressure and temperature at its core (more than a billion times that of the atmosphere on Earth, with a density about 160 times that of water).

At the core, the temperature is 16 million degrees kelvin (K), which is sufficient to sustain thermonuclear fusion reactions. The released energy prevents the collapse of the Sun and keeps it in gaseous form. The total energy radiated is 383 billion trillion kilowatts, which is equivalent to the energy generated by 100 billion tons of TNT exploding each second.

In addition to the energy-producing solar core, the interior has two distinct regions: a radiative zone and a convective zone. From the edge of the core outward, first through the radiative zone and then through the convective zone, the temperature decreases from 8 million to 7,000 K. It takes a few hundred thousand years for photons to escape from the dense core and reach the surface.

The Sun's "surface," known as the photosphere, is just the visible 500-km-thick layer from which most of the Sun's radiation and light finally escape, and it is the place where sunspots are found. Above the photosphere lies the chromosphere ("sphere of color") that may be seen briefly during total solar eclipses as a reddish rim, caused by hot hydrogen atoms, around the Sun. Temperature steadily increases with altitude up to 50,000 K, while density drops to 100,000 times less than in the photosphere. Above the chromosphere lies the corona ("crown"), extending outward from the Sun in the form of the "solar wind" to the edge of the solar system. The corona is extremely hot -

millions of degrees kelvin. Since it is physically impossible to transfer thermal energy from the cooler surface of the Sun to the much hotter corona, the source of coronal heating has been a scientific mystery for more than 60 years. Scientists believe that energy transfer has to be in the form of waves or magnetic energy. Likely solutions have emerged from recent SOHO and TRACE satellite observations, which found evidence for the upward transfer of magnetic energy from the Sun's surface toward the corona above. Researchers in NASA's Sun-Earth Connection Space Science theme study these myserious phenomena.

Earth's Moon

The regular daily and monthly rhythms of Earth's only natural satellite, the Moon, have guided timekeepers for thousands of years. Its influence on Earth's cycles, notably tides, has also been charted by many cultures in many ages. More than 70 spacecraft have been sent to the Moon; 12 astronauts have walked upon its surface and brought back 382 kg (842 pounds) of lunar rock and soil to Earth.

The presence of the Moon stabilizes Earth's wobble. This has led to a much more stable climate over billions of years, which may have affected the course of the development and growth of life on Earth.

How did the Moon come to be? The leading theory is that a Mars-sized body once hit Earth and the resulting debris (from both Earth and the impacting body) accumulated to form the Moon. Scientists believe that the Moon was formed approximately 4.5 billion years ago (the age of the oldest collected lunar rocks). When the Moon formed, its outer layers melted under very high temperatures, forming the lunar crust, probably from a global "magma ocean."

From Earth, we see the same face of the Moon all the time because the Moon rotates just once on its own axis in very nearly the same time that it travels once around Earth. This is known as "synchronous rotation." Patterns of dark and light features on the nearside have given rise to the fanciful "Man in the Moon" description. The light areas are lunar highlands. The dark features, called maria, are impact basins that were filled with dark lava between 4 and 2.5 billion years ago.

After this time of volcanism, the Moon cooled down, and has since been nearly unchanged, except for a steady rain of "hits" by meteorites and comets. The Moon's surface is charcoal gray and sandy, with much fine soil. This powdery blanket is called the lunar regolith, a term for mechanically produced debris layers on planetary surfaces. The regolith is thin, ranging from about 2 meters on the youngest maria to perhaps 20 meters on the oldest surfaces in the highlands.

Unlike Earth, the Moon does not have moving crustal plates or active volcanoes. However, seismometers planted by the Apollo astronauts in the 1970s have recorded small quakes at depths of several hundred kilometers. The quakes are probably triggered by tides resulting from Earth's gravitational pull. Small eruptions of gas from some craters, such as Aristarchus, have also been reported. Local magnetic areas have been detected around craters, but the Moon does not have a magnetic field resembling Earth's.

A surprising discovery from the tracking of the Lunar Orbiter spacecraft in the 1960s revealed strong areas of high gravitational acceleration located over the circular maria. These mass concentrations (mas-cons) may be caused by layers of denser, basaltic lavas that fill the mare basins.

In 1998, the Lunar Prospector spacecraft team reported finding water ice at both poles. Comet impacts deposited water on the Moon. Some of it migrated to very dark, very cold areas at the poles.

Much remains to be learned about our Moon. Researchers continue to study the samples and data returned by Apollo and other missions, as well as lunar meteorites.

Earth's Moon: Facts & Figures

Discovered By: Known by the Ancients

Date of Discovery: Unknown

Average Distance from Earth

Metric: 384,400 km
English: 238,855 miles
Scientific Notation: 3.84400 x 105 km (0.00257 A.U.)
By Comparison: 0.00257 x Earth's Distance from the Sun

Perigee (closest)

Metric: 363,300 km
English: 225,700 miles
Scientific Notation: 3.633 x 105 km (0.00271 A.U.)
By Comparison: 0.00247 x Earth's Distance from the Sun

Apogee (farthest)

Metric: 405,500 km
English: 252,000 miles
Scientific Notation: 4.055 x 105 km (0.00243 A.U.)
By Comparison: 0.00267 x Earth's Distance from the Sun

Equatorial Radius

Metric: 1737.4 km
English: 1079.6 miles
Scientific Notation: 1.734 x 103 km
By Comparison: 0.2724 x Earth

Equatorial Circumference

Metric: 10,916 km
English: 6,783 miles
Scientific Notation: 1.0916 x 104 km

Volume

Metric: 21,970,000 km3
Scientific Notation: 2.197 x 1010 km3
By Comparison: 0.020 x Earth

Mass

Metric: 73,483,000,000,000,000,000,000 kg
Scientific Notation: 7.3483 x 1022 kg
By Comparison: 0.0123 x Earth

Density

Metric: 3.341 g/cm3
By Comparison: 0.606 x Earth

Surface Area

Metric: 37,932,330 km2
English: 14,645,750 square miles
Scientific Notation: 3.793233 x 107 km2
By Comparison: 0.074 x Earth

Equatorial Surface Gravity

Metric: 1.622 m/s2
English: 5.322 ft/s2
By Comparison: 0.166 x Earth

Escape Velocity

Metric: 8,568 km/h
English: 5,324 mph
Scientific Notation: 2,380 m/s
By Comparison: 0.213 x Earth

Sidereal Rotation Period (Length of Day)

27.321661 Earth days
655.72 hours
By Comparison: Synchronous With Earth

Sidereal Orbit Period (Length of Year)

0.075 Earth years
27.321661 Earth days
By Comparison: Orbit Period = Rotation Period

Mean Orbit Velocity

Metric: 3,682.8 km/h
English: 2,288.4 mph
Scientific Notation: 1,023 m/s
By Comparison: 0.034 x Earth

Orbital Eccentricity

0.05490
By Comparison: 3.285 x Earth

Orbital Inclination to Ecliptic

5.145 degrees
By Comparison: Oscillates roughly 0.15 degrees in 173 days.

Equatorial Inclination to Orbit

6.68 degrees

Orbital Circumference

Metric: 2,290,000 km
English: 1,423,000 miles
Scientific Notation: 2.290 x 106 km

Minimum/Maximum Surface Temperature

Metric: -233/123 °C
English: -387/253 °F
Scientific Notation: 40/396 K

The Planets

Our solar system is huge. There is a lot of empty space out there between the planets. Voyager 1 the most distant human-made object, has been in space for more than 25 years and it still has not escaped the influence of our Sun. As of July 19, 2004, Voyager 1 was about 13,800,000,000 km from the Sun - more than twice the distance from the Sun to icy Pluto.

Needless to say, our solar system doesn't fit real well on paper - or a website for that matter.

Scientists figured out a while ago that writing out those huge numbers wasn't the best use of their time so they invented the Astronomical Unit (AU). One AU - 150,000,000 km represents the average distance from the Sun to the Earth. It would take an airliner more than 20 years to fly that distance - and that's just a one-way ticket. (That's traveling at about 644 km per hour.)

In another effort to bring these vast distances down to Earth, we've shrunk the solar system down to the size of a football field.

On a football field scale, the Sun is about as big as a dime. Considering a typical honeybee is about 12 mm long, the fans are going to need telescopes to see the action.

The inner planets - Mercury, Venus, Earth and Mars - are about the size of grains of sand on a football field scale. They would be dwarfed by a typical flea, which is about 3 mm long.

Closest to the goal line is Mercury, just under a yard from the end zone (.8 yards to be specific). In reality, the average distance from the Sun to Mercury is roughly 58,000,000 km (35,000,000 miles) or 0.4 AU. At this scale, Mercury's 0.06 mm diameter is scarcely as large as the point of a needle.

Venus is next. It is 1.4 yards from the end zone. The true average distance from the Sun to Venus is about 108,000,000 km (67,000,000 miles) or 0.7 AU. Its size on this scale is about 0.15 mm.

On to Earth, sitting pretty on the 2-yard line. It is slightly larger than Venus at about 0.16 mm.

Just as most quarterbacks would be extremely pleased to find their team within two yards of a touchdown, Earth reaps many benefits from this prime location in the solar system. We are at the perfect distance from the Sun for life to flourish. Venus is too hot. Mars is too cold. Scientists sometimes call our region of space the "Goldilocks Zone" because it appears to be just right for life.

As noted earlier, Earth's average distance to the Sun is about 150,000,000 km (93,000,000 miles) from the Sun. That's 1 AU.

Mars is on the three-yard line of our imaginary football field. The red planet is about 228,000,000 km (142,000,000 miles) on average from the Sun. That's 1.5 AU. On this scale, Mars is about 0.08 mm.

Asteroids roam far and wide in our solar system. But most are contained within the main asteroid belt between Jupiter and Mars. On our football field, you'd find them scattered like so many slow-moving linebackers between the four and eight yard lines. In real distances that's an average of roughly 300,000,000 to 600,000,000 km (186,000,000 to 372,000,000 miles) from the Sun, or 2 to 4 AU.

On this imaginary scale, these so-called "linebackers" are more like microscopic specks than the real hulking linebackers that play for the NFL. (If you could lump together all the thousands of known asteroids in our solar system, their total mass wouldn't even equal 10 percent of Earth's moon.)

Jupiter remains pretty close to our end zone on the 10.5-yard line. Our solar system's largest planet is an average distance of 778,000,000 km (484,000,000 miles) from the Sun. That's 5.2 AU. Jupiter is the largest of the planets, spanning nearly 1.75 mm in diameter on our football field scale. Jupiter's diameter is about equal to the thickness of a U.S quarter in our shrunken solar system.

Saturn is on the field at 19 yards from the goal line. The ringed world is about 1,427,000,000 km (887,000,000 miles) from the Sun, or 9.5 AU. Saturn's size on this scale: 1.47 mm.

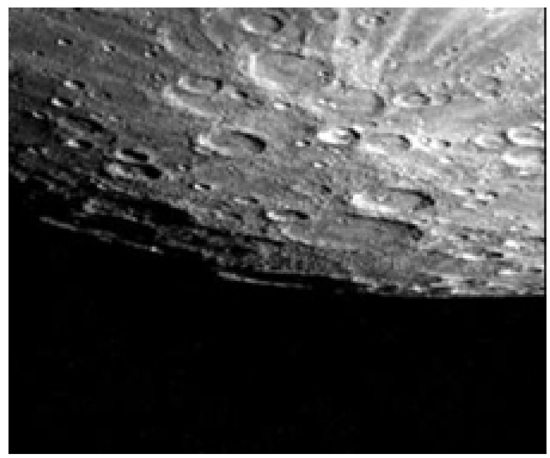
Uranus is about the point where our cosmic coach would call in an interplanetary field goal kicker. The gas giant is about 38 yards from our end zone. In real distances, that's an average of 2,871,000,000 km (1,784,000,000 miles) - 19 AU - from the Sun. That's quite a kick. It's little wonder only one spacecraft has visited Uranus. At 0.62 mm on this scale, Uranus is just a little smaller than the letter "R" in the word "TRUST" on a penny.

Neptune is where things start to get way out. It is 60 yards from our solar goal line on the imaginary football field. That's an average of 4,498,000,000 km (2,795,000000 miles) or 30 AU from the real Sun. Neptune, a little smaller than Uranus, is 0.6 mm on this scale.

Tiny Pluto is much closer to the opposing team's end zone. It's about 79 yards out from the Sun or 5,906,000,000 km (3,670,000,000 miles) on average in real distances. That's 39.5 AU.

Mercury:

The small and rocky planet Mercury is the closest planet to the Sun; it speeds around the Sun in a wildly elliptical (non-circular) orbit that takes it as close as 47 million km and as far as 70 million km from the Sun. Mercury completes a trip around the Sun every 88 days, speeding through space at nearly 50 km per second, faster than any other planet.



Because it is so close to the Sun, temperatures on its surface can reach a scorching 467 degrees Celsius. But because the planet has hardly any atmosphere to keep it warm, nighttime temperatures can drop to a frigid -183 degrees Celsius.

Because Mercury is so close to the Sun, it is hard to see from Earth except during twilight. Until 1965, scientists thought that the same side of Mercury always faced the Sun. Then, astronomers discovered that Mercury completes three rotations for every two orbits around the Sun. If you wanted to stay up for a Mercury day, you'd have to stay up for 176 Earth days.

Like our Moon, Mercury has almost no atmosphere. What little atmosphere exists is made up of atoms blasted off its surface by the solar wind and has less than a million-billionths the pressure of Earth's atmosphere at sea level. It is composed chiefly of oxygen, sodium, and helium. Because of Mercury's extreme surface temperature, these atoms quickly escape into space and are constantly replenished. With no atmosphere to protect the surface, there has been no erosion from wind or water, and meteorites do not burn up due to friction as they do in other planetary atmospheres. Mercury's surface very much resembles Earth's Moon, scarred by thousands of impact craters resulting from collisions with meteors. While there are areas of smooth terrain, there are also cliffs, some soaring up to a mile high, formed by ancient impacts.

The Caloris Basin, one of the largest features on Mercury, is about 1,300 km in diameter. It was the result of an asteroid impact on the planet's surface early in the solar system's history, the probable cause of the strange surfaces on the opposite side of the planet. Over the next half-billion years, Mercury actually shrank in radius from 2 to 4 km as the planet cooled from its formation. The outer crust, called the lithosphere, was compressed and grew strong enough to prevent the planet's magma from reaching the surface, effectively ending the planet's period of geologic activity. Evidence of Mercury's active past is seen in the smooth plains in the Caloris basin.

Mercury is the second smallest planet in the solar system, larger only than Pluto, the most distant planet in our solar system. If Earth were the size of a baseball, Mercury would be the size of a golf ball. Viewed from Mercury, the Sun would look almost three times as large as it does from Earth. Mercury is the second densest body in the solar system after Earth, with an interior made of a large iron core with a radius of 1,800 to 1,900 km, nearly 75 percent of the planet's diameter and nearly the size of Earth's Moon. Mercury's outer shell, comparable to Earth's outer shell (called the mantle) is only 500 to 600 km thick.

Only one spacecraft has ever visited Mercury: Mariner 10 in 1974-75. Mariner 10's discovery that Mercury has a very weak magnetic field, similar to but weaker than Earth's, was a major surprise. In 1991, astronomers using radar observations showed that Mercury may have water ice at its north and south poles. The ice exists inside deep craters. The floors of these craters remain in perpetual shadow, so the Sun cannot melt the ice.

Mercury: Facts & Figures

Discovered By: Known by the Ancients

Date of Discovery: Unknown

Average Distance from the Sun

Metric: 57,909,175 km
English: 35,983,095 miles
Scientific Notation: 5.7909175 x 107 km (0.38709893 A.U.)
By Comparison: Earth is 1 A.U. (Astronomical Unit) from the Sun.

Perihelion (closest)

Metric: 46,000,000 km
English: 28,580,000 miles
Scientific Notation: 4.600 x 107 km (0.3075 A.U.)
By Comparison: 0.313 x Earth

Aphelion (farthest)

Metric: 69,820,000 km
English: 43,380,000 miles
Scientific Notation: 6.982 x 107 km (0.4667 A.U.)
By Comparison: 0.459 x Earth

Equatorial Radius

Metric: 2,439.7 km
English: 1,516.0 miles
Scientific Notation: 2.4397 x 103 km
By Comparison: 0.3825 x Earth

Equatorial Circumference

Metric: 15,329.1 km
English: 9,525.1 miles
Scientific Notation: 1.53291 x 104 km

Volume

Metric: 60,827,200,000 km3
English: 14,593,200,000 mi3
Scientific Notation: 6.08272 x 1010 km3
By Comparison: 0.054 x Earth's

Mass

Metric: 330,220,000,000,000,000,000,000 kg
Scientific Notation: 3.3022 x 1023 kg
By Comparison: 0.055 x Earth's

Density

Metric: 5.427 g/cm3
By Comparison: 0.984 x Earth

Surface Area

Metric: 74,800,000 km2
English: 28,900,000 square miles
Scientific Notation: 7.48 x 107 km2
By Comparison: 0.108 x Earth

Equatorial Surface Gravity

Metric: 3.7 m/s2
English: 12.1 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 38 pounds on Mercury.

Escape Velocity

Metric: 15,300 km/h
English: 9,500 mph
Scientific Notation: 4.25 x 103 m/s
By Comparison: Escape Velocity of Earth is 25,022 mph

Sidereal Rotation Period (Length of Day)

58.646 Earth days
1407.5 hours
By Comparison: 58.81 x Earth

Sidereal Orbit Period (Length of Year)

0.241 Earth years
87.97 Earth days
By Comparison: 0.241 x Earth

Mean Orbit Velocity

Metric: 172,341 km/h
English: 107,088 mph
Scientific Notation: 47,872.5 m/s
By Comparison: 1.61 x Earth

Orbital Eccentricity

0.20563069
By Comparison: 12.3 x Earth

Orbital Inclination to Ecliptic

7 degrees

Equatorial Inclination to Orbit

0 degrees
By Comparison: Earth's equatorial inclination to orbit is 23.45 degrees.

Orbital Circumference

Metric: 356,000,000 km
English: 221,000,000 miles
Scientific Notation: 3.56 x 108 km
By Comparison: 0.385 x Earth

Minimum/Maximum Surface Temperature

Metric: -173/427 °C
English: -279/801 °F
Scientific Notation: 100/700 K
By Comparison: Earth's temperature range is ~ 185/331 K.

Atmospheric Constituents

By Comparison: Earth's atmosphere consists mostly of N2, O2

Venus:

At first glance, if Earth had a twin, it would be Venus. The two planets are similar in size, mass, composition, and distance from the Sun. But there the similarities end. Venus has no ocean. Venus is covered by thick, rapidly spinning clouds that trap surface heat, creating a scorched greenhouse-like world with temperatures hot enough to melt lead and pressure so intense that standing on Venus would feel like the pressure felt 900 meters deep in Earth's oceans.

These clouds reflect sunlight in addition to trapping heat. Because Venus reflects so much sunlight, it is usually the brightest planet in the sky.

The atmosphere consists mainly of carbon dioxide (the same gas that produces fizzy sodas), droplets of sulfuric acid, and virtually no water vapor - not a great place for people or plants! In addition, the thick atmosphere allows the Sun's heat in but does not allow it to escape, resulting in surface temperatures over 450 °C, hotter than the surface of the planet Mercury, which is closest to the Sun. The high density of the atmosphere results in a surface pressure 90 times that of Earth, which is why probes that have landed on Venus have only survived several hours before being crushed by the incredible pressure. In the upper layers, the clouds move faster than hurricane- force winds on Earth.

Venus sluggishly rotates on its axis once every 243 Earth days, while it orbits the Sun every 225 days - its day is longer than its year! Besides that, Venus rotates retrograde, or "backwards," spinning in the opposite direction of its orbit around the Sun. From its surface, the Sun would seem to rise in the west and set in the east.

Earth and Venus are similar in density and chemical compositions, and both have relatively young surfaces, with Venus appearing to have been completely resurfaced 300 to 500 million years ago.

Scientists used radar to peer through the clouds and map the surface

of Venus.
The surface of Venus is covered by about 20 percent lowland plains, 70 percent rolling uplands, and 10 percent highlands. Volcanism, impacts, and deformation of the crust have shaped the surface. No direct evidence of currently active volcanoes has been found, although large variations of sulfur dioxide in the atmosphere lead some scientists to suspect that volcanoes may be active.

Although no rainfall, oceans, or strong winds exist to erode surface features, some weathering and erosion does occur. The surface is brushed by gentle winds, no stronger than a few kilometers per hour, enough to move grains of sand, and radar images of the surface show wind streaks and sand dunes. In addition, the corrosive atmosphere probably chemically alters rocks. Impact cratering is also affected by the dense atmosphere: craters smaller than 1.5 to 2 km across do not exist on Venus, largely because small meteors burn up in Venus? dense atmosphere before they can reach the surface.

More than 1,000 volcanoes or volcanic centers larger than 20 km in diameter dot the surface of Venus. There may be close to a million volcanic centers that are over 1 km in diameter. Much of the surface is covered by vast lava flows. In the north, an elevated region named Ishtar Terra is a lava-filled basin larger than the continental United States. Near the equator, the Aphrodite Terra highlands, more than half the size of Africa, extend for almost 10,000 km. Volcanic flows have also produced long, sinuous chan-nels extending for hundreds of kilometers.

With few exceptions, features on Venus are named for accomplished women from all of Earth's cultures.

Venus' interior is probably very similar to that of Earth, containing an iron core about 3,000 km in radius and a molten rocky mantle covering the majority of the planet. Recent results from the Magellan spacecraft suggest that Venus' crust is stronger and thicker than had previously been thought. Venus has no satellites and no intrinsic magnetic field, but the solar wind rushing by Venus creates a pseudo-field around the planet

Venus: Facts & Figures

Discovered By: Known by the Ancients

Date of Discovery: Unknown

Average Distance from the Sun

Metric: 108,208,930 km
English: 67,237,910 miles
Scientific Notation: 1.0820893 x 108 km (.723332 A.U.)
By Comparison: 0.723 x Earth

Perihelion (closest)

Metric: 107,476,000 km
English: 66,782,000 miles
Scientific Notation: 1.07476 x 108 km (0.718 A.U.)
By Comparison: 0.730 x Earth

Aphelion (farthest)

Metric: 108,942,000 km
English: 67,693,000 miles
Scientific Notation: 1.08942 x 108 km (0.728 A.U.)
By Comparison: 0.716 x Earth

Equatorial Radius

Metric: 6,051.8 km
English: 3,760.4 miles
Scientific Notation: 6.0518 x 103 km
By Comparison: 0.9488 x Earth

Equatorial Circumference

Metric: 38,025 km
English: 23,627 miles
Scientific Notation: 3.8025 x 104 km

Volume

Metric: 928,400,000,000 km3
Scientific Notation: 9.284 x 1011 km3
By Comparison: 0.88 x Earth's

Mass

Metric: 4,868,500,000,000,000,000,000,000 kg
Scientific Notation: 4.8685 x 1024 kg
By Comparison: 0.815 x Earth

Density

Metric: 5.24 g/cm3
By Comparison: Comparable to the average density of the Earth.

Surface Area

Metric: 460,200,000 km2
English: 177,700,000 square miles
Scientific Notation: 4.602 x 108 km2
By Comparison: 0.902 x Earth

Equatorial Surface Gravity

Metric: 8.87 m/s2
English: 29.1 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 91 pounds on Venus.

Escape Velocity

Metric: 37,300 km/h
English: 23,200 mph
Scientific Notation: 1.036 x 104 m/s
By Comparison: 0.927 x Earth

Sidereal Rotation Period (Length of Day)

-243 Earth days (retrograde)
-5832 hours (retrograde)
By Comparison: 244 x Earth

Sidereal Orbit Period (Length of Year)

0.615 Earth years
224.7 Earth days
By Comparison: 0.615 x Earth

Mean Orbit Velocity

Metric: 126,077 km/h
English: 78,341 mph
Scientific Notation: 35,021.4 m/s
By Comparison: 1.176 x Earth

Orbital Eccentricity

.0068
By Comparison: 0.405 x Earth

Orbital Inclination to Ecliptic

3.39 degrees

Equatorial Inclination to Orbit

177.3 degrees
By Comparison: 7.56 x Earth

Orbital Circumference

Metric: 675,300,000 km
English: 419,600,000 miles
Scientific Notation: 6.753 x 108 km
By Comparison: 0.731 x Earth

Minimum/Maximum Surface Temperature

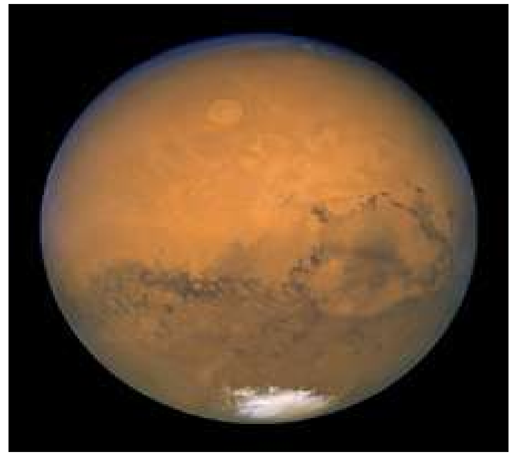
Metric: 462 °C
English: 864 °F
Scientific Notation: 735 K

Atmospheric Constituents

Carbon Dioxide, Nitrogen
Scientific Notation: CO_2, N_2
By Comparison: Earth's atmosphere consists mostly of N_2 and O_2.
CO_2 is largely responsible for the Greenhouse Effect and is used for carbonation in beverages.
N_2 is 80% of Earth's air and is a crucial element in DNA.

Mars:

The red planet Mars has inspired wild flights of imagination over the centuries, as well as intense scientific interest. Whether fancied to be the source of hostile invaders of Earth, the home of a dying civilization, or a rough-and-tumble mining colony of the future, Mars provides fertile ground for science fiction writers, based on seeds planted by centuries of scientific observations.



We know that Mars is a small rocky body once thought to be very Earth-like. Like the other "terrestrial" planets - Mercury, Venus, and Earth - its surface has been changed by volcanism, impacts from other bodies, movements of its crust, and atmospheric effects such as dust storms. It has polar ice caps that grow and recede with the change of seasons; areas of layered soils near the Martian poles suggest that the planet's climate has changed more than once, perhaps caused by a regular change in the planet's orbit. Martian tectonism - the formation and change of a planet's crust - differs from Earth's. Where Earth tectonics involve sliding plates that grind against each other or spread apart in the seafloors, Martian tectonics seem to be vertical, with hot lava pushing upwards through the crust to the surface. Periodically, great dust storms engulf the entire planet. The effects of these storms are dramatic, including giant dunes, wind streaks, and wind-carved features.

Scientists believe that 3.5 billion years ago, Mars experienced the largest known floods in the solar system. This water may even have pooled into lakes or shallow oceans. But where did the ancient flood water come from, how long did it last, and where did it go?

In May 2002, scientists announced the discovery of a key piece in the puzzle: the Mars Odyssey spacecraft had detected large quantities of water ice close to the surface - enough to fill Lake Michigan twice over. The ice is mixed into the soil only a meter (about 3 feet) below the surface of a wide area near the Martian south pole.

Many questions remain. At present, Mars is too cold and its atmosphere is too thin to allow liquid water to exist at the surface for long. More water exists frozen in the polar ice caps, and enough water exists to form ice clouds, but the quantity of water required to carve Mars' great channels and flood plains is not evident on - or near - the surface today. Images from NASA's Mars Global Surveyor spacecraft suggest that underground reserves of water may break through the surface as springs. The answers may lie deep beneath Mars' red soil.

Unraveling the story of water on Mars is important to unlocking its past climate history, which will help us understand the evolution of all planets, including our own. Water is also believed to be a central ingredient for the initiation of life; the evidence of past or present water on Mars is expected to hold clues about past or present life on Mars, as well as the potential for life elsewhere in the universe. And, before humans can safely go to Mars, we need to know much more about the planet's environment, including the availability of resources such as water.

Mars has some remarkable geological characteristics, including the largest volcanic mountain in the solar system, Olympus Mons (27 km high and 600 km across); volcanoes in the northern Tharsis region that are so huge they deform the planet's roundness; and a gigantic equatorial rift valley, the Valles Marineris. This canyon system stretches a distance equivalent to the distance from New York to Los Angeles; Arizona's Grand Canyon could easily fit into one of the side canyons of this great chasm.

Mars also has two small moons, Phobos and Deimos. Although no one knows how they formed, they may be asteroids snared by Mars' gravity.

Mars: Facts & Figures

Discovered By: Known by the Ancients

Date of Discovery: Unknown

Average Distance from the Sun

Metric: 227,936,640 km
English: 141,633,260 miles
Scientific Notation: 2.2793664 x 108 km (1.523662 A.U.)
By Comparison: 1.524 x Earth

Perihelion (closest)

Metric: 206,600,000 km
English: 128,400,000 miles
Scientific Notation: 2.066 x 108 km (1.381 A.U.)
By Comparison: 1.404 x Earth

Aphelion (farthest)

Metric: 249,200,000 km
English: 154,900,000 miles
Scientific Notation: 2.492 x 108 km (1.666 A.U.)
By Comparison: 1.638 x Earth

Equatorial Radius

Metric: 3,397 km
English: 2,111 miles
Scientific Notation: 3.397 x 103 km
By Comparison: 0.5326 x Earth

Equatorial Circumference

Metric: 21,344 km
English: 13,263 miles
Scientific Notation: 2.1344 x 104 km

Volume

Metric: 163,140,00,000 km3
Scientific Notation: 1.6314 X 1011 km3
By Comparison: 0.150 x Earth

Mass

Metric: 641,850,000,000,000,000,000,000 kg
Scientific Notation: 6.4185 x 1023 kg
By Comparison: 0.10744 x Earth

Density

Metric: 3.94 g/cm3
By Comparison: 0.714 x Earth

Surface Area

Metric: 144,100,000 km2
English: 89,500,000 square miles
Scientific Notation: 1.441 x 108 km2
By Comparison: 0.282 x Earth

Equatorial Surface Gravity

Metric: 3.693 m/s2
English: 12.116 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 38 pounds on Mars.

Escape Velocity

Metric: 18,072 km/h
English: 11,229 mph
Scientific Notation: 5.02 x 103 m/s
By Comparison: Escape velocity of Earth is 25,022 mph.

Sidereal Rotation Period (Length of Day)

1.026 Earth days
24.62 hours
By Comparison: Earth's rotation period is 23.934 hours.

Sidereal Orbit Period (Length of Year)

1.8807 Earth years
686.93 Earth days

Mean Orbit Velocity

Metric: 86,871 km/h
English: 53,979 mph
Scientific Notation: 24,130.9 m/s
By Comparison: 0.810 x Earth

Orbital Eccentricity

.0934
By Comparison: 5.59 x Earth

Orbital Inclination to Ecliptic

1.8 degrees

Equatorial Inclination to Orbit

25.19

Orbital Circumference

Metric: 1.366,900,000 km
English: 849,400,000 miles
Scientific Notation: 1.3669 x 109 km
By Comparison: 1.479 x Earth

Minimum/Maximum Surface Temperature

Metric: -87 to -5 °C
English: -125 to 23 °F
Scientific Notation: 186 to 268 K

Atmospheric Constituents

Carbon Dioxide, Nitrogen, Argon
Scientific Notation: CO_2, N_2, Ar
By Comparison: CO_2 is responsible for the Greenhouse Effect and is used for carbonation in beverages.
N_2 is 80% of Earth's air and is a crucial element in DNA. Ar is used to make blue neon light blubs.

Jupiter:

With its numerous moons and several rings, the Jupiter system is a "mini-solar system." Jupiter is the most massive planet in our solar system, and in composition it resembles a small star. In fact, if Jupiter had been between fifty and one hundred times more massive, it would have become a star rather than a planet.

On January 7, 1610, while skygazing from his garden in Padua, Italy, astronomer Galileo Galilei was surprised to see four small "stars" near Jupiter. He had discovered Jupiter's four largest moons, now called Io, Europa, Ganymede, and Callisto. Collectively, these four moons are known today as the Galilean satellites.

Galileo would be astonished at what we have learned about Jupiter and its moons in the past 30 years. Io is the most volcanically active body in our solar system. Ganymede is the largest planetary moon and has its own magnetic field. A liquid ocean may lie beneath the frozen crust of Europa. An icy ocean may also lie beneath the crust of Callisto. In 2003 alone, astronomers discovered 23 new moons orbiting the giant planet. Jupiter now officially has 63 moons - by far the most in the solar system. Many of the outer moons are probably asteroids captured by the giant planet's gravity.

At first glance, Jupiter appears striped. These stripes are dark belts and light zones created by strong east-west winds in Jupiter's upper atmosphere. Within these belts and zones are storm systems that have raged for years. The southern hemisphere's Great Red Spot has existed for at least 100 years, and perhaps longer, as Galileo reported seeing a similar feature nearly 400 years ago. Three Earths could fit across the Great Red Spot. Jupiter's core is probably not solid but a dense, hot liquid with a consistency like thick soup. The pressure inside Jupiter may be 30 million times greater than the pressure at Earth's surface.

As Jupiter rotates, a giant magnetic field is generated in its electrically conducting liquid interior. Trapped within Jupiter's magnetosphere - the area in which magnetic field lines encircle the planet from pole to pole - are enough charged particles to make the inner portions of Jupiter's magnetosphere the most deadly radiation environment of any of the planets, both for humans and for electronic equipment. The "tail" of Jupiter's magnetic field - that portion stretched behind the planet as the solar wind rushes past - has been detected as far as Saturn's orbit. Jupiter's rings and moons are embedded in an intense radiation belt of electrons and ions trapped in the magnetic field. The Jovian magnetosphere, which comprises these particles and fields, balloons one to three extending more than one billion kilometers behind Jupiter - as far as Saturn's orbit.

Discovered in 1979 by NASA's Voyager 1 spacecraft, Jupiter's rings were a surprise: a flattened main ring and an inner cloud-like ring, called the halo, are both composed of small, dark particles. A third ring, known as the gossamer ring because of its transparency, is actually three rings of microscopic debris from three small moons: Amalthea, Thebe, and Adrastea. Jupiter's ring system may be formed by dust kicked up as interplanetary meteoroids smash into the giant planet's four small inner moons. The main ring probably comes from the tiny moon Metis.

In December 1995, NASA's Galileo spacecraft dropped a probe into Jupiter's atmosphere. Carrying six scientific instruments, the probe survived the crushing pressure and searing heat for nearly an hour, collecting the first direct measurements of Jupiter's atmosphere, the first real data about the chemistry of a gas planet. Following the release of the probe, the Galileo spacecraft began a multi-year orbit of Jupiter, observing each of the largest moons from close range several times.

Jupiter: Facts & Figures

Discovered By: Known by the Ancients

Date of Discovery: Unknown

Average Distance from the Sun

Metric: 778,412,020 km
English: 483,682,810 miles
Scientific Notation: 7.7841202 x 108 km (5.20336 A.U.)
By Comparison: 5.203 x Earth

Perihelion (closest)

Metric: 740,742,600 km
English: 460,276,100 miles
Scientific Notation: 7.407426 x 108 km (4.952 A.U.)
By Comparison: 5.036 x Earth

Aphelion (farthest)

Metric: 816,081,400 km
English: 507,089,500 miles
Scientific Notation: 8.160814 x 108 km (5.455 A.U.)
By Comparison: 5.366 x Earth

Equatorial Radius

Metric: 71,492 km
English: 44,423 miles
Scientific Notation: 7.1492 x 104 km
By Comparison: 11.209 x Earth

Equatorial Circumference

Metric: 449,197 km
English: 279,118 miles
Scientific Notation: 4.49197 x 105 km

Volume

Metric: 1,425,500,000,000,000 km3
English: 342,000,000,000,000 mi3
Scientific Notation: 1.4255 x 1015 km3
By Comparison: 1316 x Earth

Mass

Metric: 1,898,700,000,000,000,000,000,000,000 kg
Scientific Notation: 1.8987 x 1027 kg
By Comparison: 317.82 x Earth

Density

Metric: 1.33 g/cm3
By Comparison: 0.241 x Earth

Surface Area

Metric: 62,179,600,000 km2
English: 24,007,700,000 square miles
Scientific Notation: 6.21796 x 1010 km2
By Comparison: 121.9 x Earth

Equatorial Surface Gravity

Metric: 20.87 m/s2
English: 68.48 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 214 pounds on Jupiter.

Escape Velocity

Metric: 214,300 km/h
English: 133,200 mph
Scientific Notation: 59,540 m/s
By Comparison: 5.33 x Earth

Sidereal Rotation Period (Length of Day)

0.41354 Earth days
9.925 hours
By Comparison: 0.4147 x Earth

Sidereal Orbit Period (Length of Year)

11.8565 Earth years
4330.6 Earth days

Mean Orbit Velocity

Metric: 47,051 km/h
English: 29,236 mph
Scientific Notation: 13,069.7 m/s
By Comparison: 0.0439 x Earth

Orbital Eccentricity

.04839
By Comparison: 2.90 x Earth

Orbital Inclination to Ecliptic

1.305 degrees

Equatorial Inclination to Orbit

3.12 degrees
By Comparison: 0.0178 x Earth

Orbital Circumference

Metric: 4,774,000,000 km
English: 2,996,000,000 miles
Scientific Notation: 4.774 x 109 km
By Comparison: 5.165 x Earth

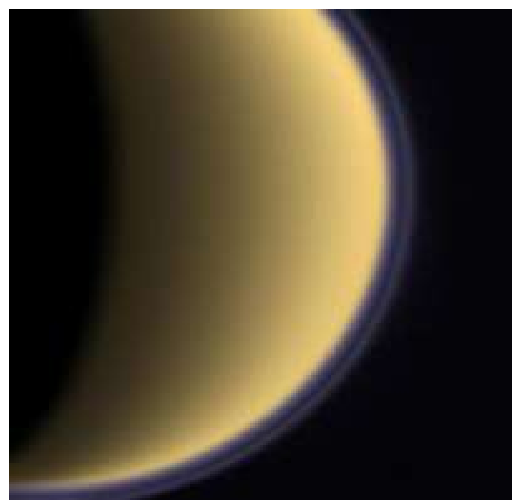
Effective Temperature

Metric: -148 °C
English: -234 °F
Scientific Notation: 125 K

Atmospheric Constituents

Hydrogen, Helium
Scientific Notation: H_2, He

Saturn:



Saturn is the most distant of the five planets known to ancient stargazers. In 1610, Italian Galileo Galilei was the first astronomer to gaze at Saturn through a telescope. To his surprise, he saw a pair of objects on either side of the planet, which he later drew as "cup handles" attached to the planet on each side. In 1659, Dutch astronomer Christiaan Huygens announced that this was a ring encircling the planet.

In 1675, Italian-born astronomer Jean Dominique Cassini discovered a gap between what are now called the A and B rings.

Like Jupiter, Uranus, and Neptune, Saturn is a gas giant. It is made mostly of hydrogen and helium. Its volume is 755 times greater than Earth's. Winds in the upper atmosphere reach 500 meters per second in the equatorial region. (In contrast, the strongest hurricane-force winds on Earth top out at about 110 meters per second.) These super-fast winds, combined with heat rising from within the planet's interior, cause the yellow and gold bands visible in its atmosphere.

Saturn's ring system is the most extensive and complex in our solar system; it extends hundreds of thousands of kilometers from the planet. In fact, Saturn and its rings would just fit in the distance between Earth and the Moon. In the early 1980s, NASA's two Voyager spacecraft revealed that Saturn's rings are made mostly of water ice, and they found "braided" rings, ringlets, and "spokes" - dark features in the rings that seem to circle the planet at a different rate from that of the surrounding ring material. Some of the small moons orbit within the ring system as well. Material in the rings ranges in size from a few micrometers to several tens of meters.

Saturn has 34 known natural satellites (moons) and there are probably many more waiting to be discovered. The largest, Titan, is a bit bigger than the planet Mercury. Titan is shrouded in a thick nitrogen-rich atmosphere that might be similar to what Earth's was like long ago. Further study of this moon promises to reveal much about planetary formation and, perhaps, about the early days of Earth as well.

In addition to Titan, Saturn has many smaller icy satellites. From Enceladus, which shows evidence of surface changes, to Iapetus, with one hemisphere darker than asphalt and the other as bright as snow, each of Saturn's satellites is unique.

Saturn, the rings, and many of the satellites lie totally within Saturn's enormous magnetosphere, the region of space in which the behavior of electrically charged particles is influenced more by Saturn's magnetic field than by the solar wind. Images taken by NASA's Hubble Space Telescope show that Saturn's polar regions have aurorae similar to Earth's Northern and Southern Lights. Aurorae occur when charged particles spiral into a planet's atmosphere along magnetic field lines.

Saturn: Facts & Figures

Discovered By: Known by the Ancients

Date of Discovery: Unknown

Average Distance from the Sun

Metric: 1,426,725,400 km
English: 885,904,700 miles
Scientific Notation: 1.4267254 x 109 km (9.53707 A.U.)
By Comparison: 9.53707 x Earth

Perihelion (closest)

Metric: 1,349,467,000 km
English: 838,519,000 miles
Scientific Notation: 1.349467 x 109 km (9.021 A.U.)
By Comparison: 9.177 x Earth

Aphelion (farthest)

Metric: 1,503,983,000 km
English: 934,530,000 miles
Scientific Notation: 1.503983 x 109 km (10.054 A.U.)
By Comparison: 9.886 x Earth

Equatorial Radius

Metric: 60,268 km
English: 37,449 miles
Scientific Notation: 6.0268 x 104 km
By Comparison: 9.449 x Earth

Equatorial Circumference

Metric: 378,675 km
English: 235,298 miles
Scientific Notation: 3.78675 x 105 km

Volume

Metric: 827,130,000,000,000 km3
Scientific Notation: 8.2713 x 1014 km3
By Comparison: 763.6 x Earth

Mass

Metric: 568,510,000,000,000,000,000,000,000 kg
Scientific Notation: 5.6851 x 1026 kg
By Comparison: 95.16 x Earth

Density

Metric: 0.70 g/cm3
By Comparison: 0.127 x Earth

Surface Area

Metric: 43,466,000,000 km2
English: 16,782,000,000 square miles
Scientific Notation: 4.3466 x 1010 km2
By Comparison: 85.22 x Earth

Equatorial Surface Gravity

Metric: 7.207 m/s2
English: 23.64 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 74 pounds on Saturn.

Escape Velocity

Metric: 127,760 km/h
English: 79,390 mph
Scientific Notation: 35,490 m/s
By Comparison: Escape velocity of Earth is 25,022 mph.

Sidereal Rotation Period (Length of Day)

0.44401 Earth days
10.656 hours
By Comparison: .0445 x Earth

Sidereal Orbit Period (Length of Year)

29.4 Earth years
10755.7 Earth days

Mean Orbit Velocity

Metric: 34,821 km/h
English: 21,637 mph
Scientific Notation: 9,672.4 m/s
By Comparison: 0.865 x Earth

Orbital Eccentricity

.0541506
By Comparison: 3.24 x Earth

Orbital Inclination to Ecliptic

2.484 degrees

Equatorial Inclination to Orbit

26.73 degrees
By Comparison: 1.14 x Earth

Orbital Circumference

Metric: 8,725,000,000 km
English: 5,421,000,000 miles
Scientific Notation: 8.725 x 109 km
By Comparison: 9.439 x Earth

Effective Temperature

Metric: -178 °C
English: -288 °F
Scientific Notation: 95 K

Atmospheric Constituents

Hydrogen, Helium
Scientific Notation: H2, He
By Comparison: Earth's atmosphere consists mostly of N2 and O2.

Uranus:

Once considered one of the blander-looking planets, Uranus (pronounced YOOR un nus) has been revealed as a dynamic world with some of the brightest clouds in the outer solar system and 11 rings. Uranus gets its blue-green color from methane gas above the deeper cloud layers (methane absorbs red light and reflects blue light).

Uranus was discovered in 1781 by astronomer William Herschel, who at first believed it to be a comet. This seventh planet from the Sun is

so distant that it takes 84 years to complete an orbit.
Uranus is classified as a "gas giant" planet because it has no solid surface. The atmosphere of Uranus is hydrogen and helium, with a small amount of methane and traces of water and ammonia. The bulk (80 percent or more) of the mass of Uranus is contained in an extended liquid core consisting primarily of "icy" materials (water, methane, and ammonia), with higher-density material at depth.

In 1986, Voyager 2 observed faint cloud markings in the southern latitudes blowing westward between 100 and 600 km/hr. In 1998, the Hubble Space Telescope observed as many as 20 bright clouds at various altitudes in Uranus' atmosphere. The bright clouds are probably made of crystals of methane, which condense as warm bubbles of gas well up from deep in the atmosphere of Uranus.

Uranus currently moves around the Sun with its rotation axis nearly horizontal with respect to the ecliptic plane. This unusual orientation may be the result of a collision with a planet-sized body early in the planet's history, which apparently changed Uranus' rotation radically. Uranus' magnetic field is unusual in that the magnetic axis is tilted 60 degrees from the planet's axis of rotation and is offset from the center of the planet by one-third of the planet's radius.

Uranus is so far from the Sun that, even though tipped on its side and experiencing seasons that last over twenty years, the temperature differences on the summer and winter sides of the planet do not differ that greatly. Near the cloudtops, the temperature of Uranus is near -215 °C.

Uranus' rings were first discovered in 1977. The rings are in the planet's equatorial plane, perpendicular to its orbit about the Sun. The 10 outer rings are dark, thin, and narrow, while the 11th ring is inside the other ten and is broad and diffuse. The rings of Uranus are very different from those surrounding Jupiter and Saturn. When viewed with the Sun behind the rings, fine dust can be seen scattered throughout all of the rings.

Uranus is named for an ancient Greek sky god. It has 27 known moons, named mostly for characters from the works of Shakespeare and Alexander Pope. Miranda is the strangest Uranian moon. The high cliffs and winding valleys of the moon may indicate partial melting of the interior, with icy material occasionally drifting to the surface.

Uranus: Facts & Figures

Discovered By: William Herschel

Date of Discovery: 1781

Average Distance from the Sun

Metric: 2,870,972,200 km
English: 1,783,939,400 miles
Scientific Notation: 2.8709722 x 109 km (19.191 A.U.)
By Comparison: 19.191 x Earth

Perihelion (closest)

Metric: 2,735,560,000 km
English: 1,699,800,000 miles
Scientific Notation: 2.73556 x 109 km (18.286 A.U.)
By Comparison: 18.60 x Earth

Aphelion (farthest)

Metric: 3,006,390,000 km
English: 1,868,080,000 miles
Scientific Notation: 3.00639 x 109 km (20.096 A.U.)
By Comparison: 19.76 x Earth

Equatorial Radius

Metric: 25,559 km
English: 15,882 miles
Scientific Notation: 2.5559 x 104 km
By Comparison: 4.007 x Earth

Equatorial Circumference

Metric: 160,592 km
English: 99,787 miles
Scientific Notation: 1.60592 x 105 km

Volume

Metric: 69,142,000,000,000 km3
Scientific Notation: 5.9142 x 1013 km3
By Comparison: 63.1 x Earth

Mass

Metric: 86,849,000,000,000,000,000,000,000 kg
Scientific Notation: 8.6849 x 1025 kg
By Comparison: 14.371 x Earth's

Density

Metric: 1.30 g/cm3
By Comparison: 0.236 x Earth

Surface Area

Metric: 8,115,600,000 km2
English: 3,133,400,000 square miles
Scientific Notation: 8.1156 x 109 km2
By Comparison: 15.91 x Earth

Equatorial Surface Gravity

Metric: 8.43 m/s2
English: 27.7 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 86 pounds on Uranus.

Escape Velocity

Metric: 76,640 km/h
English: 47,620 mph
Scientific Notation: 21,290 m/s
By Comparison: 1.904 x Earth

Sidereal Rotation Period (Length of Day)

-0.7196 Earth days (retrograde)
-17.24 hours (retrograde)
By Comparison: 0.722 x Earth

Sidereal Orbit Period (Length of Year)

84.02 Earth years
30,687.2 Earth days

Mean Orbit Velocity

Metric: 24,607 km/h
English: 15,290 mph
Scientific Notation: 6,835.2 m/s
By Comparison: 0.229 x Earth

Orbital Eccentricity

.047168
By Comparison: 2.823 x Earth

Orbital Inclination to Ecliptic

0.770 degrees

Equatorial Inclination to Orbit

97.86 degrees
By Comparison: 4.173 x Earth

Orbital Circumference

Metric: 17,620,000,000 km
Scientific Notation: 1.762 x 1010 km
By Comparison: 19.06 x Earth

Effective Temperature

Metric: -216 °C
English: -357 °F
Scientific Notation: 57 K

Atmospheric Constituents

Hydrogen, Helium, Methane
Scientific Notation: H_2, He, CH_4
By Comparison: Earth's atmosphere consists mostly of N_2 and O_2.

Neptune:

The eighth planet from the Sun, Neptune was the first planet located through mathematical predictions rather than through regular observations of the sky. When Uranus didn't travel exactly as astronomers expected it to, two mathematicians, working independently of each other, proposed the position and mass of another, as yet unknown planet that could account for Uranus' orbit.

Although "the establishment" ignored the predictions, a young astronomer decided to look for the predicted planet. Thus, Neptune was discovered in 1846. Seventeen days later, its largest moon, Triton, was also discovered.

Nearly 4.5 billion kilometers from the Sun, Neptune orbits the Sun once every 165 years, and therefore it has not quite made a full circle around the Sun since it was discovered. It is invisible to the naked eye because of its extreme distance from Earth. Interestingly, due to Pluto's unusual elliptical orbit, Neptune is actually the farthest planet from the Sun for a 20-year period out of every 248 Earth years.

Neptune has the smallest diameter of our solar system's giant gas planets (including Jupiter, Saturn, and Uranus), so called because they have no solid surfaces. Even so, its volume could hold nearly 60 Earths. Neptune's atmosphere extends to great depths, gradually merging into water and other "melted ices" over a heavier, approximately Earth-sized liquid core. Neptune's rotational axis is tilted 30 degrees to the plane of its orbit around the Sun. Its seasons last an incredible 41 years. During the southern summer, the south pole is in constant sunlight for about 41 years, and in northern summer, the north pole is in constant sunlight for about 41 years. Neptune's atmosphere is made up of hydrogen, helium, and methane, the last of these giving the planet its blue color (because methane absorbs red light). Despite its great distance from the Sun and lower energy input, Neptune's winds are three times stronger than Jupiter's and nine times stronger than Earth's.

In 1989, Voyager 2 tracked a large oval dark storm in Neptune's south-ern hemisphere. This hurricane-like "Great Dark Spot" was large enough to contain the entire Earth; spun counterclockwise; and moved westward at almost 1,200 km per hour. Recent images from the Hubble Space Telescope show no sign of the "Great Dark Spot," although a comparable spot appeared in 1997 in Neptune's northern hemisphere.

The planet has several rings of varying widths, confirmed by Voyager 2's observations in 1989. The outermost ring, Adams, contains five distinct arcs (incomplete rings) named Liberté, Equalité 1, Equalité 2, Fraternité, and Courage. Next is an unnamed ring coorbital with the moon Galatea, then Le Verrier, Lassell, Arago, and Galle. Neptune's rings are believed to be relatively young and relatively short-lived.

Neptune has 13 known moons, six of which were discovered by Voyager 2. The largest, Triton, orbits Neptune in a direction opposite to the planet's rotation direction, and is gradually getting closer until it will collide with the planet in about 10 to 100 million years, forming vast rings around Neptune that will rival or exceed Saturn's extensive ring system. Triton is the coldest body yet visited in our solar system; temperatures on its surface are about -235 °C. Despite the deep freeze, Voyager 2 discovered great geysers of gaseous nitrogen on Triton.

Neptune: Facts & Figures

Discovered By: Johann Galle

Date of Discovery: 1846

Average Distance from the Sun

Metric: 4,498,252,900 km
English: 2,795,084,800 miles
Scientific Notation: 4.4982529 x 109 km (30.069 A.U.)
By Comparison: 30.069 x Earth

Perihelion (closest)

Metric: 4,459,630,000 km
English: 2,771,087,000 miles
Scientific Notation: 4.45963 x 109 km (29.811 A.U.)
By Comparison: 29.820 x Earth

Aphelion (farthest)

Metric: 4,536,870,000 km
English: 2,819,080,000 miles
Scientific Notation: 4.53687 x 109 km (30.327 A.U.)
By Comparison: 30.326 x Earth

Equatorial Radius

Metric: 24,764 km
English: 15,388 miles
Scientific Notation: 2.4764 x 105 km
By Comparison: 3.883 x Earth

Equatorial Circumference

Metric: 155,597 km
English: 96,683 miles
Scientific Notation: 1.55597 x 105 km

Volume

Metric: 62,526,000,000,000 km3
Scientific Notation: 6.2526 x 1013 km3
By Comparison: 57.7 x Earth's

Mass

Metric: 102,440,000,000,000,000,000,000,000 kg
Scientific Notation: 1.0244 x 1026 kg
By Comparison: 17.147 x Earth's

Density

Metric: 1.76 g/cm3
By Comparison: 0.317 x Earth

Surface Area

Metric: 7,640,800,000 km2
English: 2,950,100,000 square miles
Scientific Notation: 7.6408 x 109 km2
By Comparison: 14.980 x Earth

Equatorial Surface Gravity

Metric: 10.71 m/s2
English: 35.14 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 110 pounds on Neptune.

Escape Velocity

Metric: 85,356 km/h
English: 53,038 mph
Scientific Notation: 23,710 m/s
By Comparison: Escape velocity of Earth is 25,022 mph.

Sidereal Rotation Period (Length of Day)

0.67125 Earth days
16.11 hours
By Comparison: 0.673 x Earth

Sidereal Orbit Period (Length of Year)

164.79 Earth years
60,190 Earth days

Mean Orbit Velocity

Metric: 19,720 km/h
English: 12,253 mph
Scientific Notation: 5,477.8 m/s
By Comparison: 0.490 x Earth

Orbital Eccentricity

.00859
By Comparison: 0.514 x Earth

Orbital Inclination to Ecliptic

1.769 degrees

Equatorial Inclination to Orbit

29.58 degrees
By Comparison: 1.261 x Earth

Orbital Circumference

Metric: 28,142,000,000 km
English: 17,487,000,000 miles
Scientific Notation: 2.8142 x 1010 km
By Comparison: 30.44 x Earth

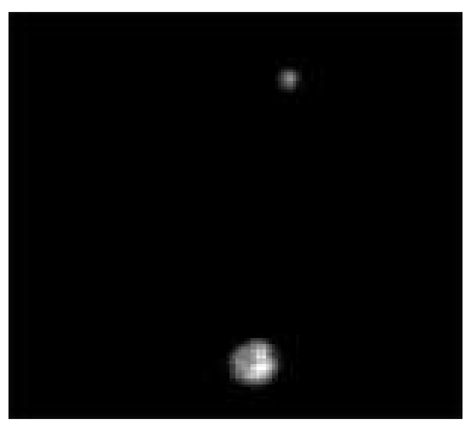
Effective Temperature

Metric: -214 °C
English: -353 °F
Scientific Notation: 59 K

Atmospheric Constituents

Hydrogen, Helium, Methane
Scientific Notation: H2, He, CH4
By Comparison: Earth's atmosphere consists mostly of N2 and O2.

Pluto:



Long considered to be the smallest, coldest, and most distant planet from the Sun, Pluto may also be the largest of a group of objects that orbit in a disk-like zone of beyond the orbit of Neptune called the Kuiper Belt. This distant region consists of thousands of miniature icy worlds with diameters of at least 1,000 km and is also believed to be the source of some comets.

Discovered by American astronomer Clyde Tombaugh in 1930, Pluto takes 248 years to orbit the Sun. Pluto's most recent close approach to the Sun was in 1989. Between 1979 and 1999, Pluto's highly elliptical orbit brought it closer to the Sun than Neptune, providing rare opportunities to study this small, cold, distant world and its companion moon, Charon.

Most of what we know about Pluto we have learned since the late 1970s from Earth-based observations, the Infrared Astronomical Satellite (IRAS), and the Hubble Space Telescope. Many of the key questions about Pluto, Charon, and the outer fringes of our solar system await close-up observations by a robotic space flight mission.

Pluto and and Charon orbit the Sun in a region where there may be a population of hundreds or thousands of similar bodies that were formed early in solar system history. These objects are referred to interchangeably as trans-Neptunian objects, Edgeworth-Kuiper Disk objects or ice dwarves.

Pluto is about two-thirds the diameter of Earth's Moon and may have a rocky core surrounded by a mantle of water ice. Due to its lower density, its mass is about one-sixth that of the Moon. Pluto appears to have a bright layer of frozen methane, nitrogen, and carbon monoxide on its surface. While it is close to the Sun, these ices thaw, rise, and temporarily form a thin atmosphere, with a pressure one one-millionth that of Earth's atmosphere. Pluto's low gravity (about 6 percent of Earth's) causes the atmosphere to be much more extended in altitude than our planet's. Because Pluto's orbit is so elliptical, Pluto grows much colder during the part of each orbit when it is traveling away from the Sun. During this time, the bulk of the planet's atmosphere freezes.

In 1978, American astronomers James Christy and Robert Harrington discovered that Pluto has a satellite (moon), which they named Charon. Charon is almost half the size of Pluto and shares the same orbit. Pluto and Charon are thus essentially a double planet. Charon's surface is covered with dirty water ice and doesn't reflect as much light as Pluto's surface.

No spacecraft have visited Pluto. NASA is currently considering a mission called New Horizons that would explore both Pluto and the Kuiper Belt region. The earliest it would launch is 2006.

Because Pluto is so small and far away, it is difficult to observe from Earth. In the late 1980s, Pluto and Charon passed in front of each other repeatedly for several years. Observations of these rare events allowed astronomers to make crude maps of each body. From these maps it was learned that Pluto has polar caps, as well as large, dark spots nearer its equator.

Pluto: Facts & Figures

Discovered By: Clyde Tombaugh

Date of Discovery: 1930

Average Distance from the Sun

Metric: 5,906,380,000 km
English: 3,670,050,000 miles
Scientific Notation: 5.90638 x 109 km (39.482 A.U.)
By Comparison: 39.482 x Earth

Perihelion (closest)

Metric: 4,436,820,000 km
English: 2,756,902,000 miles
Scientific Notation: 4.43682 x 109 km (29.658 A.U.)
By Comparison: 30.171 x Earth

Aphelion (farthest)

Metric: 7,375,930,000 km
English: 4,583,190,000 miles
Scientific Notation: 7.37593 x 109 km (49.305 A.U.)
By Comparison: 48.481 x Earth

Equatorial Radius

Metric: 1,151 km
English: 715 miles
Scientific Notation: 1.151 x 103 km
By Comparison: 0.180 x Earth

Equatorial Circumference

Metric: 7,232 km
English: 4,494 miles
Scientific Notation: 7.232 x 103 km

Volume

Metric: 6,390,000,000 km3
English: 1,530,000,000 mi3
Scientific Notation: 6.39 x 109 km3
By Comparison: 0.0059 x Earth

Mass

Metric: 13,000,000,000,000,000,000,000 kg
Scientific Notation: 1.3 x 1022 kg
By Comparison: 0.0022 x Earth

Density

Metric: 2 g/cm3
By Comparison: ~ 0.4 x Earth

Surface Area

Metric: 16,650,000 km2
English: 6,430,000 square miles
Scientific Notation: 1.665 x 107 km2
By Comparison: 0.033 x Earth

Equatorial Surface Gravity

Metric: 0.81 m/s2
English: 2.7 ft/s2
By Comparison: If you weigh 100 pounds on Earth, you would weigh 8 pounds on Pluto.

Escape Velocity

Metric: 4,570 km/h
English: 2,840 mph
Scientific Notation: 1,270 m/s
By Comparison: Escape velocity of Earth is 25,022 mph.

Sidereal Rotation Period (Length of Day)

6.387 Earth days
153.3 hours
By Comparison: One Earth day is 24 hours.

Sidereal Orbit Period (Length of Year)

247.92 Earth years
90,553 Earth days

Mean Orbit Velocity

Metric: 17,096 km/h
English: 10,623 mph
Scientific Notation: 4,749.0 m/s
By Comparison: 0.425 x Earth

Orbital Eccentricity

0.2488
By Comparison: 14.9 x Earth

Orbital Inclination to Ecliptic

17.14 degrees

Equatorial Inclination to Orbit

119.61 degrees
By Comparison: 5.10 x Earth

Orbital Circumference

Metric: 32,820,000,000 km
English: 20,390,000,000 miles
Scientific Notation: 3.282 x 1010 km
By Comparison: 35.505 x Earth

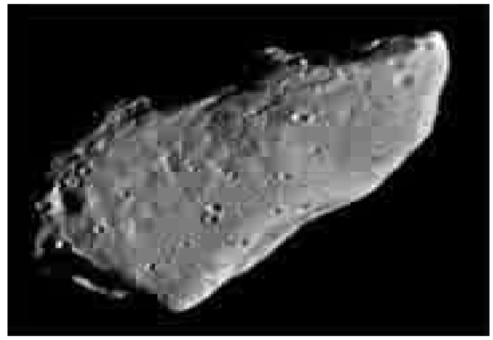
Minimum/Maximum Surface Temperature

Metric: -233/-223 °C
English: -387/-369 °F
Scientific Notation: 40/50 K

Atmospheric Constituents

By Comparison: Earth's atmosphere consists mostly of N2 and O2.

Asteroids



Asteroids are rocky fragments left over from the formation of the solar system about 4.6 billion years ago. Most of these fragments of ancient space rubble - sometimes referred to by scientists as minor planets - can be found orbiting the Sun in a belt between Mars and Jupiter.

This region in our solar system, called the Asteroid Belt or Main Belt, probably contains millions of asteroids ranging widely in size from Ceres, which at 940 km in diameter is about one-quarter the diameter of our Moon, to bodies that are less than 1 km across. There are more than 90,000 numbered asteroids.

As asteroids revolve around the Sun in elliptical orbits, giant Jupiter's gravity and occasional close encounters with Mars or with another asteroid change the asteroids' orbits, knocking them out of the Main Belt and hurling them into space across the orbits of the planets. For example, Mars' moons Phobos and Deimos may be captured asteroids. Scientists believe that stray asteroids or fragments of asteroids have slammed into Earth in the past, playing a major role both in altering the geological history of our planet and in the evolution of life on it. The extinction of the dinosaurs 65 million years ago has been linked to a devastating impact near the Yucatan peninsula in Mexico.

Asteroids were first observed with telescopes in the early 1800s, and in 1802, the astronomer William Herschel first used the word "asteroid," which means "starlike" in Greek, to describe these celestial bodies. Most of what we have learned about asteroids in the past 200 years has been derived from telescopic observations. Ground-based telescopes are used to watch asteroids that orbit close to Earth, not only to detect new ones or keep track of them, but also to watch for any asteroids that might collide with Earth in the future. Scientists define near-Earth asteroids (NEAs) as those whose orbits never take them farther than about 195 million kilometers from the Sun.

In the last few decades, astronomers have used instruments called spectroscopes to determine the chemical and mineral composition of asteroids by analyzing the light reflected off their surfaces. Scientists also examine meteorites - the remains of comets or asteroids that can be found on Earth - for clues to the origin of these bodies. About three-quarters of asteroids are extremely dark and are similar to carbon-rich meteorites called carbonaceous chondrites (C-type). About one-sixth of asteroids are reddish, stony-iron bodies (S-type).

In 1997, instruments on the Hubble Space Telescope mapped Vesta, one of the largest asteroids, and found an enormous crater formed a billion years ago. Interestingly, Vesta is an uncommon asteroid type, yet meteorites having the same composition have been found on Earth. Could these be remnants from the collision that created Vesta's giant crater?

NASA's Galileo spacecraft was the first to observe an asteroid close-up, fly-ing by main-belt asteroids Gaspra and Ida in 1991 and 1993, respectively. Gaspra and Ida proved to be irregularly shaped objects, rather like potatoes, riddled with craters and fractures, 19 km long and 52 km long respectively. Galileo also discovered that Ida has its own moon, Dactyl, a tiny body in orbit around the asteroid that may be a fragment from past collisions.

NASA's Near-Earth Asteroid Rendezvous (NEAR) mission was the first dedicated scientific mission to an asteroid. The NEAR Shoemaker spacecraft caught up with asteroid Eros in February 2000 and orbited the small body for a year, studying its surface, orbit, mass, composition, and magnetic field. In February 2001, mission controllers guided the spacecraft to the first-ever landing on an asteroid.

Meteoroids

"Shooting stars" or meteors are bits of material falling through Earth's atmosphere; they are heated to incandescence by the friction of the air. The bright trails as they are coming through the Earth's atmosphere are termed meteors, and these chunks as they are hurtling through space are called meteoroids.

Large pieces that do not vaporize completely and reach the surface of the Earth are termed meteorites.

Scientists estimate that 1,000 tons to more than 10,000 tons of meteoritic material falls on the Earth each day. However, most of this material is very tiny - in the form of micrometeoroids or dust-like grains a few micrometers in size. (These particles are so tiny that the air resistance is enough to slow them sufficiently that they do not burn up, but rather fall gently to Earth.)

Where do they come from? They probably come from within our own solar system, rather than interstellar space. Their composition provides clues to their origins. They may share a common origin with the asteroids. Some meteoritic material is similar to the Earth and Moon and some is quite different. Some evidence indicates an origin from comets.

Several "shooting stars" or meteors per hour can usually be seen on any given night. Sometimes the number of meteors seen increases dramatically: these are termed "meteor showers". In fact, some meteor showers occur annually or at rather regular intervals. The number is greater in autumn and winter. The number always increases after midnight and is usually greatest just before dawn. Perhaps the most famous are the Perseids which peak around August 12 every year.

Meteor showers are usually named after a star or constellation which is close to the radiant (the position from which the meteors appear to come). Many of the meteor showers are associated with comets. The Leonids are associated with Comet Tempel-Tuttle; Aquarids and Orionids with Halley, and the Taurids with Encke.

Meteorites may look very much like Earth rocks, or they may have a burned appearance. They may be dense metallic chunks or more rocky. Some may have thumbprint-like depressions, roughened or smooth exteriors. They vary in size from micrometer size grains to large individual boulders. The largest individual iron is the Hoba meteorite from southwest Africa which has a mass of about 54,000 kg. The stones are much smaller, the largest falling in Norton County, Kansas having a mass of about 1,000 kg.

Considering the vast infall of meteorites, one cannot help but wonder if anyone has been hurt or killed by meteorites. There are only a few documented cases on record. A shower of stones fell upon Nakhla, near Alexandria, Egypt on June 28, 1911, one of which allegedly killed a dog. On November 30, 1954, Mrs. Hewlett Hodges of Sylacauga, Alabama was severely bruised by an 8 pound stony meteorite that crashed through her roof. This is the first known human injury.

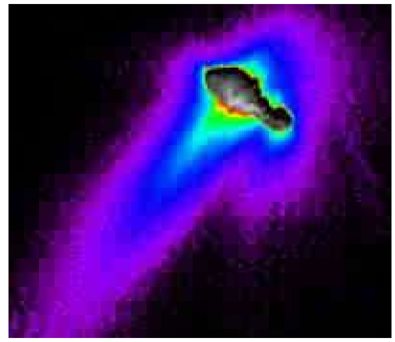
Most meteoritic samples are either iron (actually nickel-iron alloy); stony,which are predominately rocky-silicates; or stony-iron.

While most meteors burn up before reaching the Earth's surface, many meteoroids break apart in the upper atmosphere, and become "fluffy meteors". This "fluffy" nature indicates a loose structure or vapor grown crystal aggregates. This gives rise to theories that some meteoroid material was aggregated, some subjected to heating-vaporization-condensation. This contrasts with the idea that meteoroids originated from an exploded planet or planetoid or asteroid.

Sixteen meteorites have been found in Antarctica that are believed to have originated on the planet Mars. Gases trapped in these meteorites match the composition of the martian atmosphere as measured by the Viking spacecraft ,which landed on Mars in the mid-1970s. Controversy continues about whether structures found in one of these meteorites, known as ALH 84001, might be fossil bacteria or geologic structures.

Much remains to be learned about meteorites and their origins.

Comets



Throughout history, people have been both awed and alarmed by comets, stars with "long hair" that appeared in the sky unannounced and unpredictably. We now know that comets are dirty-ice leftovers from the formation of our solar system around 4.6 billion years ago.

They are among the least-changed objects in our solar system and, as such, may yield important clues about the formation of our solar system. We can predict the orbits of many of them, but not all.

Around a dozen "new" comets are discovered each year. Short-period comets are more predictable because they take less than 200 years to orbit the Sun. Most come from a region of icy bodies beyond the orbit of Neptune. These icy bodies are variously called Kuiper Belt Objects, Edgeworth-Kuiper Belt Objects, or trans-Neptunian objects. Less predictable are long-period comets, many of which arrive from a distant region called the Oort cloud about 100,000 astronomical units (that is, 100,000 times the mean distance between Earth and the Sun) from the Sun. These comets can take as long as 30 million years to complete one trip around the Sun. (It takes Earth only 1 year to orbit the Sun.) As many as a trillion comets may reside in the Oort cloud, orbiting the Sun near the edge of the Sun's gravitational influence.

Each comet has only a tiny solid part, called a nucleus, often no bigger than a few kilometers across. The nucleus contains icy chunks and frozen gases with bits of embedded rock and dust. At its center, the nucleus may have a small, rocky core.

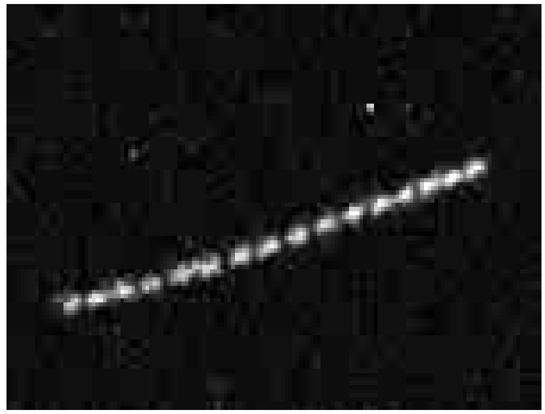
As a comet nears the Sun, it begins to warm up. The comet gets bright enough to see from Earth while its atmosphere - the coma - grows larger. The Sun's heat causes ice on the comet's surface to change to gases, which fluoresce like a neon sign. "Vents" on the Sun-warmed side may release fountains of dust and gas for tens of thousands of kilometers. The escaping material forms a coma that may be hundreds of thousands of kilometers in diameter.

The pressure of sunlight and the flow of electrically charged particles, called the solar wind, blow the coma materials away from the Sun, forming the comet's long, bright tails, which are often seen separately as straight tails of electrically charged ions and an arching tail of dust. The tails of a comet always point away from the Sun.

Most comets travel a safe distance from the Sun itself. Comet Halley comes no closer than 89 million kilometers from the Sun, which is closer to the Sun than Earth is. However, some comets, called sun-grazers, crash straight into the Sun or get so close that they break up and vaporize.

Impacts from comets played a major role in the evolution of the Earth, primarily during its early history billions of years ago. Some believe that they brought water and a variety of organic molecules to Earth

Kuiper Belt



The Kuiper (pronounced Ki-Per) Belt is often called our solar system's 'final frontier.' This disk-shaped region of icy debris is about 12 to 15 billion kilometers (7.5 billion to 9.3 billion miles) from our Sun. Its existence confirmed only a decade ago, the Kuiper Belt and its collection of icy objects - KBOs - are an emerging area of research in planetary science.

The most recent exciting discovery to come out of the Kuiper Belt is "Quaoar" (Kwa-whar), officially known as 2002 LM60, a frozen world orbiting our sun about a billion miles beyond the orbit of Pluto. The tiny world's diameter is 1,300 km (800 miles) - about half the size of Pluto. It is the largest of the more than 500 Kuiper Belt Objects discovered in the last decade. Quaoar/2002 LM60 orbits our Sun in a near circle, more so than any of the other planets or bodies in our solar system.

Quaoar is still an unofficial name. The two scientists who discovered 2002 LM60 have asked the International Astronomical Union to name the tiny world "Quaoar" in honor of a Native American creation god.

KBOs like Quaoar are tough to spot. The tiny objects are billions of kilometers from Earth and very difficult to pinpoint with ground-based telescopes. Even the powerful cameras of NASA's Hubble Space Telescope can only produce rough images. No spacecraft have visited this distant region, though NASA's proposed New Horizons spacecraft could fly through in 2026.

The Search for the Kuiper Belt

In 1950, Dutch astronomer Jan Oort hypothesized that comets came from a vast shell of icy bodies about 50,000 times farther from the Sun than the Earth. A year later astronomer Gerard Kuiper suggested that some comet-like debris from the formation of the solar system should also be just beyond Neptune. In fact, he argued, it would be unusual not to find such a continuum of particles since this would imply the primordial solar system has a discrete "edge."

This notion was reinforced by the realization that there is a separate population of comets, called the Jupiter family, that behave strikingly different than those coming from the far reaches of the Oort cloud. Besides orbiting the Sun in less than 20 years (as opposed to 200 million years for an Oort member), the comets are unique because their orbits lie near the plane of the Earth's orbit around the Sun. In addition, all these comets go around the Sun in the same direction as the planets.

Kuiper's hypothesis was reinforced in the early 1980s when computer simulations of the solar system's formation predicted that a disk of debris should naturally form around the edge of the solar system. According to this scenario, planets would have agglomerated quickly in the inner region of the Sun's primordial circumstellar disk, and gravitationally swept up residual debris. However, beyond Neptune, the last of the gas giants, there should be a debris-field of icy objects that never coalesced to form planets.

The Kuiper belt remained theory until the 1992 detection of a 150-mile wide body, called 1992QB1 at the distance of the suspected belt. Several similar-sized objects were discovered quickly confirming the Kuiper belt was real. The planet Pluto, discovered in 1930, is considered the largest member of this Kuiper belt region. Also, Neptune's satellites, Triton and Nereid, and Saturn's satellite, Phoebe are in unusual orbits and may be captured Kuiper belt objects.

Beyond Our Solar System

In 1991, the nine worlds of our own solar system were the only known planets. Astronomers did not believe that our Sun's environment was the only planet producer in the universe. But they had no evidence of planets outside our solar system.

How quickly things change.

In 1991 radio astronomers detected the first extrasolar planets orbiting a dying pulsar star. This star was left over from a supernova explosion in the constellation Virgo. The pulsar's beam of radiation changed slightly due to the gravitational pull of three Earth-sized objects revolving around the host star, PSR B1257+12. Although the deadly radiation from the pulsar is not condusive to life, it was the first example of a star other than our Sun producing planets.

In 1995 Swiss astronomers found another extra-solar planetary candidate. It was discovered by noting a slight perturbation in the position of 51 Pegasi, a star in our nearby galactic neighborhood. This star, found in the constellation of Pegasus, is much more like our Sun with respect to its temperature, size, rotation speed and emitted radiation. The newly found planet orbiting 51 Peg had a size comparable to Jupiter or Saturn, however, it was positioned extremely close to its parent star - closer than Mercury sits from our own Sun. Although not a good candidate for a life, it was the first ever evidence of an extrasolar planet around a Sun-like star.

Since then more than 100 planets have been found orbiting other stars. Some of them are orbiting extremely close to their parent star like the 51 Peg planetary system, while others are found to be at distances comparable to where Mars and Jupiter orbit in our solar system.

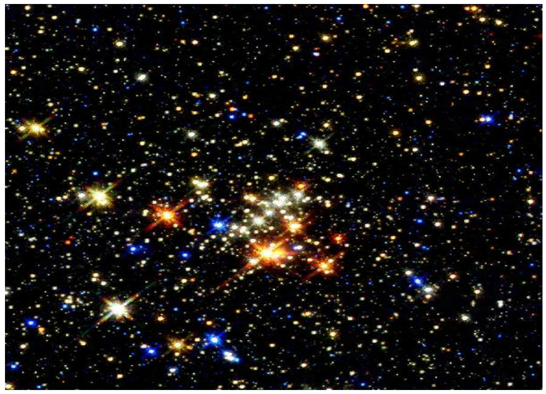
Plans for Continued Searches

The right size, the right distance, the right temperature: we finally have evidence for the existence of extrasolar worlds that may be candidates for life-bearing planets as well. A search of the nearest 1,000 stars to our Sun may reveal evidence of planets very much like Earth. "Earth-type" planets, the most condusive to sustaining life, must be solid bodies (unlike the gas giant planets in our outer solar system) with masses roughly between 0.5 - 10 Earth masses. These planets need to be found at distances from their parent star such that the planet's temperature and atmospheric pressure are supportive of the existence of liquid water.

Direct methods for examining stars in our nearby neighborhood for the existence of planets would involve the detection of starlight reflected by an orbiting planet or perhaps by the emitted thermal radiation from the planet itself. Optical reflected light and infrared thermal radiation could both be analyzed spectroscopically (provided astronomers could actually detect this gentle signal amid the powerful fury of its host star) to present information about the size, sunlight reflectivity (albedo) and temperature of a planet.

Indirect methods of planetary detection include measurements of radial velocities of nearby stars, measurements of pulsar rates, actual changes in the position of a host star based on gravitational pull of planets or changes in the apparent brightness of the host star due to transits and microlensing events. Each of these methods can indicate the presence of external bodies around nearby stars.

The Stars



A star is a huge, shining ball in space that produces a tremendous amount of light and other forms of energy. The sun is a star, and it supplies Earth with light and heat energy. The stars look like twinkling points of light -- except for the sun. The sun looks like a ball because it is much closer to Earth than any other star.

The sun and most other stars are made of gas and a hot, gaslike substance known as plasma. But some stars, called white dwarfs and neutron stars, consist of tightly packed atoms or subatomic particles. These stars are therefore much more dense than anything on Earth.

Stars come in many sizes. The sun's radius (distance from its center to its surface) is about 432,000 miles (695,500 kilometers). But astronomers classify the sun as a dwarf because other kinds of stars are much bigger. Some of the stars known as supergiants have a radius about 1,000 times that of the sun. The smallest stars are the neutron stars, some of which have a radius of only about 6 miles (10 kilometers).

About 75 percent of all stars are members of a binary system, a pair of closely spaced stars that orbit each other. The sun is not a member of a binary system. However, its nearest known stellar neighbor, Proxima Centauri, is part of a multiple-star system that also includes Alpha Centauri A and Alpha Centauri B.

The distance from the sun to Proxima Centauri is more than 25 trillion miles (40 trillion kilometers). This distance is so great that light takes 4.2 years to travel between the two stars. Scientists say that Proxima Centauri is 4.2 light-years from the sun. One light-year, the distance that light travels in a vacuum in a year, equals about 5.88 trillion miles (9.46 trillion kilometers).

Stars are grouped in huge structures called galaxies. Telescopes have revealed galaxies throughout the universe at distances of 12 billion to 16 billion light-years. The sun is in a galaxy called the Milky Way that contains more than 100 billion stars. There are more than 100 billion galaxies in the universe, and the average number of stars per galaxy may be 100 billion. Thus, more than 10 billion trillion stars may exist. But if you look at the night sky far from city lights, you can see only about 3,000 of them without using binoculars or a telescope.

Stars, like people, have life cycles -- they are born, pass through several phases, and eventually die. The sun was born about 4.6 billion years ago and will remain much as it is for another 5 billion years. Then it will grow to become a red giant. Late in the sun's lifetime, it will cast off its outer layers. The remaining core, called a white dwarf, will slowly fade to become a black dwarf.

Other stars will end their lives in different ways. Some will not go through a red giant stage. Instead, they will merely cool to become white dwarfs, then black dwarfs. A small percentage of stars will die in spectacular explosions called supernovae.

This article discusses Star (The stars at night) (Names of stars) (Characteristics of stars) (Fusion in stars) (Evolution of stars).

The stars at night

If you look at the stars on a clear night, you will notice that they seem to twinkle and that they differ greatly in brightness. A much slower movement also takes place in the night sky: If you map the location of several stars for a few hours, you will observe that all the stars revolve slowly about a single point in the sky.

Twinkling of stars is caused by movements in Earth's atmosphere. Starlight enters the atmosphere as straight rays. Twinkling occurs because air movements constantly change the path of the light as it comes through the air. You can see a similar effect if you stand in a swimming pool and look down. Unless the water is almost perfectly still, your feet will appear to move and change their shape. This "twinkling" occurs because the moving water constantly changes the path of the light rays that travel from your feet to your eyes.

Brightness of stars. How bright a star looks when viewed from Earth depends on two factors: (1) the actual brightness of the star -- that is, the amount of light energy the star emits (sends out) -- and (2) the distance from Earth to the star. A nearby star that is actually dim can appear brighter than a distant star that is really extremely brilliant. For example, Alpha Centauri A seems to be slightly brighter than a star known as Rigel. But Alpha Centauri A emits only 1/100,000 as much light energy as Rigel. Alpha Centauri A seems brighter because it is only 1/325 as far from Earth as Rigel is -- 4.4 light-years for Alpha Centauri A, 1,400 light-years for Rigel.

Rising and setting of stars

When viewed from Earth's Northern Hemisphere, stars rotate counterclockwise around a point called the celestial north pole. Viewed from the Southern Hemisphere, stars rotate clockwise about the celestial south pole. During the day, the sun moves across the sky in the same direction, and at the same rate, as the stars. These movements do not result from any actual revolution of the sun and stars. Rather, they occur because of the west-to-east rotation of Earth about its own axis. To an observer standing on the ground, Earth seems motionless, while the sun and stars seem to move in circles. But actually, Earth moves.

Names of stars

Ancient people saw that certain stars are arranged in patterns shaped somewhat like human beings, animals, or common objects. Some of these patterns, called constellations, came to represent figures of mythological characters. For example, the constellation Orion (the Hunter) is named after a hero in Greek mythology.

Today, astronomers use constellations, some of which were described by the ancients, in the scientific names of stars. The International Astronomical Union (IAU), the world authority for assigning names to celestial objects, officially recognizes 88 constellations. These constellations cover the entire sky. In most cases, the brightest star in a given constellation has alpha -- the first letter of the Greek alphabet -- as part of its scientific name. For instance, the scientific name for Vega, the brightest star in the constellation Lyra (the Harp), is Alpha Lyrae. Lyrae is Latin for of Lyra.

The second brightest star in a constellation is usually designated beta, the second letter of the Greek alphabet, the third brightest is gamma, and so on. The assignment of Greek letters to stars continues until all the Greek letters are used. Numerical designations follow.

But the number of known stars has become so large that the IAU uses a different system for newly discovered stars. Most new names consist of an abbreviation followed by a group of symbols. The abbreviation stands for either the type of star or a catalog that lists information about the star. For example, PSR J1302-6350 is a type of star known as a pulsar -- hence the PSR in its name. The symbols indicate the star's location in the sky. The 1302 and the 6350 are coordinates that are similar to the longitude and latitude designations used to indicate locations on Earth's surface. The J indicates that a coordinate system known as J2000 is being used.

Characteristics of stars

A star has five main characteristics: (1) brightness, which astronomers describe in terms of magnitude or luminosity; (2) color; (3) surface temperature; (4) size; and (5) mass (amount of matter). These characteristics are related to one another in a complex way. Color depends on surface temperature, and brightness depends on surface temperature and size. Mass affects the rate at which a star of a given size produces energy and so affects surface temperature. To make these relationships easier to understand, astronomers developed a graph called the Hertzsprung-Russell (H-R) diagram. This graph, a version of which appears in this article, also helps astronomers understand and describe the life cycles of stars.

Magnitude and luminosity

Magnitude is based on a numbering system invented by the Greek astronomer Hipparchus in about 125 B.C. Hipparchus numbered groups of stars according to their brightness as viewed from Earth. He called the brightest stars first magnitude stars, the next brightest second magnitude stars, and so on to sixth magnitude stars, the faintest visible stars.

Modern astronomers refer to a star's brightness as viewed from Earth as its apparent magnitude. But they have extended Hipparchus's system to describe the actual brightness of stars, for which they use the term absolute magnitude. For technical reasons, they define a star's absolute magnitude as what its apparent magnitude would be if it were 32.6 light-years from Earth.

Astronomers have also extended the system of magnitude numbers to include stars brighter than first magnitude and dimmer than sixth magnitude. A star that is brighter than first magnitude has a magnitude less than 1. For example, the apparent magnitude of Rigel is 0.12. Extremely bright stars have magnitudes less than zero -- that is, their designations are negative numbers. The brightest star in the night sky is Sirius, with an apparent magnitude of -1.46. Rigel has an absolute magnitude of -8.1. According to astronomers' present understanding of stars, no star can have an absolute magnitude much brighter than -8. At the other end of the scale, the dimmest stars detected with telescopes have apparent magnitudes up to 28. In theory, no star could have an absolute magnitude much fainter than 16.

Luminosity is the rate at which a star emits energy. The scientific term for a rate of energy emission is power, and scientists generally measure power in watts. For example, the luminosity of the sun is 400 trillion trillion watts. But astronomers do not usually measure a star's luminosity in watts. Instead, they express luminosities in terms of the luminosity of the sun. They often say, for instance, that the luminosity of Alpha Centauri A is about 1.3 times that of the sun and that Rigel is roughly 150,000 times as luminous as the sun.

Luminosity is related to absolute magnitude in a simple way. A difference of 5 on the absolute magnitude scale corresponds to a factor of 100 on the luminosity scale. Thus, a star with an absolute magnitude of 2 is 100 times as luminous as a star with an absolute magnitude of 7. A star with an absolute magnitude of -3 is 100 times as luminous as a star whose absolute magnitude is 2 and 10,000 times as luminous as a star that has an absolute magnitude of 7.

Color and temperature

If you look carefully at the stars, even without binoculars or a telescope, you will see a range of color from reddish to yellowish to bluish. For example, Betelgeuse looks reddish, Pollux -- like the sun -- is yellowish, and Rigel looks bluish.

A star's color depends on its surface temperature. Astronomers measure star temperatures in a metric unit known as the kelvin. One kelvin equals exactly 1 Celsius degree (1.8 Fahrenheit degree), but the Kelvin and Celsius scales start at different points. The Kelvin scale starts at -273.15 degrees C. Therefore, a temperature of 0 K equals -273.15 degrees C, or -459.67 degrees F. A temperature of 0 degrees C (32 degrees F) equals 273.15 K.

Dark red stars have surface temperatures of about 2500 K. The surface temperature of a bright red star is approximately 3500 K; that of the sun and other yellow stars, roughly 5500 K. Blue stars range from about 10,000 to 50,000 K in surface temperature.

Although a star appears to the unaided eye to have a single color, it actually emits a broad spectrum (band) of colors. You can see that starlight consists of many colors by using a prism to separate and spread the colors of the light of the sun, a yellow star. The visible spectrum includes all the colors of the rainbow. These colors range from red, produced by the photons (particles of light) with the least energy; to violet, produced by the most energetic photons.

Visible light is one of six bands of electromagnetic radiation. Ranging from the least energetic to the most energetic, they are: radio waves, infrared rays, visible light, ultraviolet rays, X rays, and gamma rays. All six bands are emitted by stars, but most individual stars do not emit all of them. The combined range of all six bands is known as the electromagnetic spectrum.

Astronomers study a star's spectrum by separating it, spreading it out, and displaying it. The display itself is also known as a spectrum. The scientists study thin gaps in the spectrum. When the spectrum is spread out from left to right, the gaps appear as vertical lines. The spectra of stars have dark absorption lines where radiation of specific energies is weak. In a few special cases in the visible spectrum, stars have bright emission lines where radiation of specific energies is especially strong.

An absorption line appears when a chemical element or compound absorbs radiation that has the amount of energy corresponding to the line. For example, the spectrum of the visible light coming from the sun has a group of absorption lines in the green part of the spectrum. Calcium in an outer layer of the sun absorbs light rays that would have produced the corresponding green colors.

Although all stars have absorption lines in the visible band of the electromagnetic spectrum, emission lines are more common in other parts of the spectrum. For instance, nitrogen in the sun's atmosphere emits powerful radiation that produces emission lines in the ultraviolet part of the spectrum.

Size

Astronomers measure the size of stars in terms of the sun's radius. Alpha Centauri A, with a radius of 1.05 solar radii (the plural of radius), is almost exactly the same size as the sun. Rigel is much larger at 78 solar radii, and Antares has a huge size of 776 solar radii.

A star's size and surface temperature determine its luminosity. Suppose two stars had the same temperature, but the first star had twice the radius of the second star. In this case, the first star would be four times as bright as the second star. Scientists say that luminosity is proportional to radius squared -- that is, multiplied by itself. Imagine that you wanted to compare the luminosities of two stars that had the same temperature but different radii. First, you would divide the radius of the larger star by the radius of the smaller star. Then, you would square your answer.

Now, suppose two stars had the same radius but the first star's surface temperature -- measured in kelvins -- was twice that of the second star. In this example, the luminosity of the first star would be 16 times that of the second star. Luminosity is proportional to temperature to the fourth power. Imagine that you wanted to compare the luminosities of stars that had the same radius but different temperatures. First, you would divide the temperature of the warmer star by the temperature of the cooler star. Next, you would square the result. Then, you would square your answer again.

Mass

Astronomers express the mass of a star in terms of the solar mass, the mass of the sun. For example, they give the mass of Alpha Centauri A as 1.08 solar masses; that of Rigel, as 3.50 solar masses. The mass of the sun is 2 ? 1030 kilograms, which would be written out as 2 followed by 30 zeros.

Stars that have similar masses may not be similar in size -- that is, they may have different densities. Density is the amount of mass per unit of volume. For instance, the average density of the sun is 88 pounds per cubic foot (1,400 kilograms per cubic meter), about 140 percent that of water. Sirius B has almost exactly the same mass as the sun, but it is 90,000 times as dense. As a result, its radius is only about 1/50 of a solar radius.

The Hertzsprung-Russell diagram displays the main characteristics of stars. The diagram is named for astronomers Ejnar Hertzsprung of Denmark and Henry Norris Russell of the United States. Working independently of each other, the two scientists developed the diagram around 1910.

Luminosity classes

Points representing the brightest stars appear toward the top of the H-R diagram; points corresponding to the dimmest stars, toward the bottom. These points appear in groups that correspond to different kinds of stars. In the 1930's, American astronomers William W. Morgan and Philip C. Keenan invented what came to be known as the MK luminosity classification system for these groups. Astronomers revised and extended this system in 1978. In the MK system, the largest and brightest classes have the lowest classification numbers. The MK classes are: Ia, bright supergiant; Ib, supergiant; II, bright giant; III, giant; IV, subgiant; and V, main sequence or dwarf.

Because temperature also affects the luminosity of a star, stars from different luminosity classes can overlap. For example, Spica, a class V star, has an absolute magnitude of -3.2; but Pollux, a class III star, is dimmer, with an absolute magnitude of 0.7.

Spectral classes

Points representing the stars with the highest surface temperatures appear toward the left edge of the H-R diagram; points representing the coolest stars, toward the right edge. In the MK system, there are eight spectral classes, each corresponding to a certain range of surface temperature. From the hottest stars to the coolest, these classes are: O, B, A, F, G, K, M, and L. Each spectral class, in turn, is made up of 10 spectral types, which are designated by the letter for the spectral class and a numeral. The hottest stars in a spectral class are assigned the numeral 0; the coolest stars, the numeral 9.

A complete MK designation thus includes symbols for luminosity class and spectral type. For example, the complete designation for the sun is G2V. Alpha Centauri A is also a G2V star, and Rigel's designation is B8Ia.

Fusion in stars

A star's tremendous energy comes from a process known as nuclear fusion. This process begins when the temperature of the core of the developing star reaches about 1 million K.

A star develops from a giant, slowly rotating cloud that consists almost entirely of the chemical elements hydrogen and helium. The cloud also contains atoms of other elements as well as microscopic particles of dust.

Due to the force of its own gravity, the cloud begins to collapse inward, thereby becoming smaller. As the cloud shrinks, it rotates more and more rapidly, just as spinning ice skaters turn more rapidly when they pull in their arms. The outermost parts of the cloud form a spinning disk. The inner parts become a roughly spherical clump, which continues to collapse.

The collapsing material becomes warmer, and its pressure increases. But the pressure tends to counteract the gravitational force that is responsible for the collapse. Eventually, therefore, the collapse slows to a gradual contraction. The inner parts of the clump form a protostar, a ball-shaped object that is no longer a cloud, but is not yet a star. Surrounding the protostar is an irregular sphere of gas and dust that had been the outer parts of the clump.

Combining nuclei

When the temperature and pressure in the protostar's core become high enough, nuclear fusion begins. Nuclear fusion is a joining of two atomic nuclei to produce a larger nucleus.

Nuclei that fuse are actually the cores of atoms. A complete atom has an outer shell of one or more particles called electrons, which carry a negative electric charge. Deep inside the atom is the nucleus, which contains almost all the atom's mass. The simplest nucleus, that of the most common form of hydrogen, consists of a single particle known as a proton. A proton carries a positive electric charge. All other nuclei have one or more protons and one or more neutrons. A neutron carries no net charge, and so a nucleus is electrically positive. But a complete atom has as many electrons as protons. The net electric charge of a complete atom is therefore zero -- the atom is electrically neutral.

However, under the enormous temperatures and pressures near the core of a protostar, atoms lose electrons. The resulting atoms are known as ions, and the mixture of the free electrons and ions is called a plasma.

Atoms in the core of the protostar lose all their electrons, and the resulting bare nuclei approach one another at tremendous speeds. Under ordinary circumstances, objects that carry like charges repel each other. However, if the core temperature and pressure become high enough, the repulsion between nuclei can be overcome and the nuclei can fuse. Scientists commonly refer to fusion as "nuclear burning." But fusion has nothing to do with ordinary burning or combustion.

Converting mass to energy

When two relatively light nuclei fuse, a small amount of their mass turns into energy. Thus, the new nucleus has slightly less mass than the sum of the masses of the original nuclei. The German-born American physicist Albert Einstein discovered the relationship E = mc-squared (E=mc 2) that indicates how much energy is released when fusion occurs. The symbol E represents the energy; m, the mass that is converted; and c-squared (c2), the speed of light squared.

The speed of light is 186,282 miles (299,792 kilometers) per second. This is such a large number that the conversion of a tiny quantity of mass produces a tremendous amount of energy. For example, complete conversion of 1 gram of mass releases 90 trillion joules of energy. This amount of energy is roughly equal to the quantity released in the explosion of 22,000 tons (20,000 metric tons) of TNT. This is much more energy than was released by the atomic bomb that the United States dropped on Hiroshima, Japan, in 1945 during World War II. The energy of the bomb was equivalent to the explosion of 13,000 tons (12,000 metric tons) of TNT.

Destruction of light nuclei

In the core of a protostar, fusion begins when the temperature reaches about 1 million K. This initial fusion destroys nuclei of certain light elements. These include lithium 7 nuclei, which consist of three protons and four neutrons. In the process involving lithium 7, a hydrogen nucleus combines with a lithium 7 nucleus, which then splits into two parts. Each part consists of a nucleus of helium 4 -- two protons and two neutrons. A helium 4 nucleus is also known as an alpha particle.

Hydrogen fusion

After the light nuclei are destroyed, the protostar continues to contract. Eventually, the core temperature reaches about 10 million K, and hydrogen fusion begins. The protostar is now a star.

In hydrogen fusion, four hydrogen nuclei fuse to form a helium 4 nucleus. There are two general forms of this reaction: (1) the proton-proton (p-p) reaction and (2) the carbon-nitrogen-oxygen (CNO) cycle.

The p-p reaction can occur in several ways, including the following four-step process:

(1) Two protons fuse. In this step, two protons collide, and then one of the protons loses its positive charge by emitting a positron. The proton also emits an electrically neutral particle called a neutrino.

A positron is the antimatter equivalent of an electron. It has the same mass as an electron but differs from the electron in having a positive charge. By emitting the positron, the proton becomes a neutron. The new nucleus therefore consists of a proton and a neutron -- a combination known as a deuteron.

(2) The positron collides with an electron that happens to be nearby. As a result, the two particles annihilate each other, producing two gamma rays.

(3) The deuteron fuses with another proton, producing a helium 3 nucleus, which consists of two protons and one neutron. This step also produces a gamma ray.

(4) The helium 3 nucleus fuses with another helium 3 nucleus. This step produces a helium 4 nucleus, and two protons are released.

The CNO cycle differs from the p-p reaction mainly in that it involves carbon 12 nuclei. These nuclei consist of six protons and six neutrons. During the cycle, they change into nuclei of nitrogen 15 (7 protons and 8 neutrons) and oxygen 15 (8 protons and 7 neutrons). But they change back to carbon 12 nuclei by the end of the cycle.

Fusion of other elements

Helium nuclei can fuse to form carbon 12 nuclei. However, the core temperature must rise to about 100 million K for this process to occur. This high temperature is necessary because the helium nuclei must overcome a much higher repulsive force than the force between two protons. Each helium nucleus has two protons, so the repulsive force is four times as high as the force between two protons.

The fusion of helium is called the triple-alpha process because it combines three alpha particles to create a carbon 12 nucleus. Helium fusion also produces nuclei of oxygen 16 (8 protons and 8 neutrons) and neon 20 (10 protons and 10 neutrons).

At core temperatures of about 600 million K, carbon 12 can fuse to form sodium 23 (11 protons, 12 neutrons), magnesium 24 (12 protons, 12 neutrons), and more neon 20. However, not all stars can reach these temperatures.

As fusion processes produce heavier and heavier elements, the temperature necessary for further processes increases. At about 1 billion K, oxygen 16 nuclei can fuse, producing silicon 28 (14 protons, 14 neutrons), phosphorus 31 (15 protons, 16 neutrons), and sulfur 32 (16 protons, 16 neutrons).

Fusion can produce energy only as long as the new nuclei have less mass than the sum of the masses of the original nuclei. Energy production continues until nuclei of iron 56 (26 protons, 30 neutrons) begin to combine with other nuclei. When this happens, the new nuclei have slightly more mass than the original nuclei. This process therefore uses energy, rather than producing it.

Evolution of stars

The life cycles of stars follow three general patterns, each associated with a range of initial mass. There are (1) high-mass stars, which have more than 8 solar masses; (2) intermediate-mass stars, with 0.5 to 8 solar masses -- the group that includes the sun; and (3) low-mass stars, with 0.1 to 0.5 solar mass. Objects with less than 0.1 solar mass do not have enough gravitational force to produce the core temperature necessary for hydrogen fusion.

The life cycles of single stars are simpler than those of binary systems, so this section discusses the evolution of single stars first. And because astronomers know much more about the sun than any other star, the discussion begins with the development of intermediate-mass stars.

Intermediate-mass stars

A cloud that eventually develops into an intermediate-mass star takes about 100,000 years to collapse into a protostar. As a protostar, it has a surface temperature of about 4000 K. It may be anywhere from a few times to a few thousand times as luminous as the sun, depending on its mass.

T-Tauri phase

When hydrogen fusion begins, the protostar is still surrounded by an irregular mass of gas and dust. But the energy produced by hydrogen fusion pushes away this material as a protostellar wind. In many cases, the disk that is left over from the collapse channels the wind into two narrow cones or jets. One jet emerges from each side of the disk at a right angle to the plane of the disk. The protostar has become a T-Tauri star, a type of object named after the star T in the constellation Taurus (the Bull). A T-Tauri star is a variable star, one that varies in brightness.

Main-sequence phase

The T-Tauri star contracts for about 10 million years. It stops contracting when its tendency to expand due to the energy produced by fusion in its core balances its tendency to contract due to gravity. By this time, hydrogen fusion in the core is supplying all the star's energy. The star has begun the longest part of its life as a producer of energy from hydrogen fusion, the main-sequence phase. The name of this phase comes from a part of the H-R diagram.

Any star -- whatever its mass -- that gets all its energy from hydrogen fusion in its core is said to be "on the main sequence" or "a main-sequence star." The amount of time a star spends there depends on its mass. The greater a star's mass, the more rapidly the hydrogen in its core is used up, and therefore the shorter is its stay on the main sequence. An intermediate-mass star remains on the main sequence for billions of years.

Red giant phase

When all the hydrogen in the core of an intermediate-mass star has fused into helium, the star changes rapidly. Because the core no longer produces fusion energy, gravity immediately crushes matter down upon it. The resulting compression quickly heats the core and the region around it. The temperature becomes so high that hydrogen fusion begins in a thin shell surrounding the core. This fusion produces even more energy than had been produced by hydrogen fusion in the core. The extra energy pushes against the star's outer layers, and so the star expands enormously.

As the star expands, its outer layers become cooler, so the star becomes redder. And because the star's surface area expands greatly, the star also becomes brighter. The star is now a red giant.

Horizontal branch phase

Eventually, the core temperature reaches 100 million K, high enough to support the triple-alpha process. This process begins so rapidly that its onset is known as helium flash.

As the triple-alpha process continues, the core expands, but its temperature drops. This decrease in temperature causes the temperature of the hydrogen-burning shell to drop. Consequently, the energy output of the shell decreases, and the outer layers of the star contract. The star becomes hotter but smaller and fainter than it had been as a red giant. This change occurs over a period of about 100 million years.

At the end of this period, the star is in its horizontal branch phase, named for the position of the point representing the star on the H-R diagram. The star steadily burns helium and hydrogen, and so its temperature, size, and luminosity do not change significantly. This phase lasts for about 10 million years.

Asymptotic giant phase

When all the helium in the core has fused, the core contracts and therefore becomes hotter. The triple-alpha process begins in a shell surrounding the core, and hydrogen fusion continues in a shell surrounding that. Due to the increased energy produced by the burning in the shells, the star's outer layers expand. The star becomes a giant again, but it is bluer and brighter than it was the first time.

On the H-R diagram, the point representing the star has moved upward and to the right along a line known as the asymptotic (as ihm TOT ihk) giant branch (AGB). The star is therefore called an AGB star.

An AGB star's core is so hot and its gravitational grip on its outermost layers is so weak that those layers blow away in a stellar wind. As each layer blows away, a hotter layer is exposed. Thus, the stellar wind becomes even stronger. Out in space, a succession of new, fast winds slam into old, slow winds that are still moving away from the star. The collisions produce dense shells of gas, some of which cool to form dust.

White dwarf phase

In just a few thousand years, all but the hot core of an AGB star blows away, and fusion ceases in the core. The core illuminates the surrounding shells. Such shells looked like planets through the crude telescopes of astronomers who studied them in the 1800's. As a result, the astronomers called the shells planetary nebulae -- and today's astronomers still do. The word nebulae is Latin for clouds.

After a planetary nebula fades from view, the remaining core is known as a white dwarf star. This kind of star consists mostly of carbon and oxygen. Its initial temperature is about 100,000 K.

Black dwarf phase

Because a white dwarf star has no fuel remaining for fusion, it becomes cooler and cooler. Over billions of years, it cools more and more slowly. Eventually, it becomes a black dwarf -- an object too faint to detect. A black dwarf represents the end of the life cycle of an intermediate-mass star.

High-mass stars, those with more than 8 solar masses, form quickly and have short lives. A high-mass star forms from a protostar in about 10,000 to 100,000 years.

High-mass stars on the main sequence are hot and blue. They are 1,000 to 1 million times as luminous as the sun, and their radii are about 10 times the solar radius. High-mass stars are much less common than intermediate- and low-mass stars. Because they are so bright, however, high-mass stars are visible from great distances, and so many are known.

A high-mass star has a strong stellar wind. A star of 30 solar masses can lose 24 solar masses by stellar wind before its core runs out of hydrogen and it leaves the main sequence.

As a high-mass star leaves the main sequence, hydrogen begins to fuse in a shell outside its core. As a result, its radius increases to about 100 times that of the sun. However, its luminosity decreases slightly. Because the star is now emitting almost the same amount of energy from a much larger surface, the temperature of the surface decreases. The star therefore becomes redder.

As the star evolves, its core heats up to 100 million K, enough to start the triple-alpha process. After about 1 million years, helium fusion ends in the core but begins in a shell outside the core. And, as in an intermediate-mass star, hydrogen fuses in a shell outside that. The high-mass star becomes a bright red supergiant.

When the contracting core becomes sufficiently hot, carbon fuses, producing neon, sodium, and magnesium. This phase lasts only about 10,000 years. A succession of fusion processes then occur in the core. Each successive process involves a different element and takes less time. Whenever a different element begins to fuse in the core, the element that had been fusing there continues to fuse in a shell outside the core. In addition, all the elements that had been fusing in shells continue to do so. Neon fuses to produce oxygen and magnesium, a process that lasts about 12 years. Oxygen then fuses, producing silicon and sulfur for about 4 years. Finally, silicon fuses to make iron, taking about a week.

Supernovae

At this time, the radius of the iron core is about 1,900 miles (3,000 kilometers). Because further fusion would consume energy, the star is now doomed. It cannot produce any more fusion energy to balance the force of gravity.

When the mass of the iron core reaches 1.4 solar masses, violent events occur. The force of gravity within the core causes the core to collapse. As a result, the core temperature rises to nearly 10 billion K. At this temperature, the iron nuclei break down into lighter nuclei and eventually into individual protons and neutrons. As the collapse continues, protons combine with electrons, producing neutrons and neutrinos. The neutrinos carry away about 99 percent of the energy produced by the crushing of the core.

Now, the core consists of a collapsing ball of neutrons. When the radius of the ball shrinks to about 6 miles (10 kilometers), the ball rebounds like a solid rubber ball that has been squeezed.

All the events from the beginning of the collapse of the core to the rebounding of the neutrons occur in about one second. But more violence is in store. The rebounding of the ball of neutrons sends a spherical shock wave outward through the star. Much of the energy of the wave causes fusion to occur in overlying layers, creating new elements. As the wave reaches the star's surface, it boosts temperatures to 200,000 K. As a result, the star explodes, hurling matter into space at speeds of about 9,000 to 25,000 miles (15,000 to 40,000 kilometers) per second. The brilliant explosion is known as a Type II supernova.

Supernovae enrich the clouds of gas and dust from which new stars eventually form. This enrichment process has been going on since the first supernovae billions of years ago. Supernovae in the first generation of stars enriched the clouds with materials that later went into making newer stars.

Three generations of stars may exist. Astronomers have not found any of what would be the oldest generation, Population III, stars. But they have found members of the other two generations. Population II stars, which would be the second generation, contain relatively small amounts of heavy elements. The more massive ones aged and died quickly, thereby contributing more nuclei of heavy elements to the clouds. For this reason, Population I stars, the third generation, contain the largest amounts of heavy elements. Yet these quantities are tiny compared with the amount of hydrogen and helium in Population I stars. For example, elements other than hydrogen and helium make up from 1 to 2 percent of the mass of the sun, a Population I star.

Neutron stars

After a Type II supernova blast occurs, the stellar core remains behind. If the core has less than about 3 solar masses, it becomes a neutron star. This object consists almost entirely of neutrons. It packs at least 1.4 solar masses into a sphere with a radius of about 6 to 10 miles (10 to 15 kilometers).

Neutron stars have initial temperatures of 10 million K, but they are so small that their visible light is difficult to detect. However, astronomers have detected pulses of radio energy from neutron stars, sometimes at a rate of almost 1,000 pulses per second.

A neutron star actually emits two continuous beams of radio energy. The beams flow away from the star in opposite directions. As the star rotates, the beams sweep around in space like searchlight beams. If one of the beams periodically sweeps over Earth, a radio telescope can detect it as a series of pulses. The telescope detects one pulse for each revolution of the star. A star that is detected in this way is known as a pulsar.

Black holes

If the stellar core remaining after the supernova explosion has about 3 or more solar masses, no known force can support it against its own gravitation. The core collapses to form a black hole, a region of space whose gravitational force is so strong that nothing can escape from it. A black hole is invisible because it traps even light. All its matter is located at a single point in its center. This point, known as a singularity, is much smaller than an atomic nucleus.

Low-mass stars, ranging from 0.1 to 0.5 solar mass, have surface temperatures less than about 4,000 K. Their luminosities are less than 2 percent of the solar luminosity. Low-mass stars use hydrogen fuel so slowly that they may shine as main-sequence stars for 100 billion to 1 trillion years. This life span is longer than the present age of the universe, believed to be 10 billion to 20 billion years. Therefore, no low-mass star has ever died. Nevertheless, astronomers have determined that low-mass stars will never fuse anything but hydrogen. Thus, as these stars die, they will not pass through a red-giant phase. Instead, they will merely cool to become white dwarfs, then black dwarfs.

Binary stars develop from two protostars that form near each other. More than 50 percent of what seem to the unaided eye to be single stars are actually binaries.

One star in a binary system can affect the life cycle of the other if the two stars are sufficiently close together. Between the stars is a location called the Lagrange point, named for the French mathematician Joseph Louis Lagrange, where the star's gravitational forces are exactly equal. If one of the stars expands so much that its outer layers pass the Lagrange point, the other star will begin to strip away those layers and accumulate them on its surface.

This process, called mass transfer, can take many forms. Mass transfer from a red giant onto a main-sequence companion can add absorption lines of carbon or other elements to the spectrum of the main-sequence star. But if the stars are close together, the material will flow in the opposite direction when the giant star becomes a white dwarf. The matter will spiral in toward the dwarf, forming a hot disk around it.

The disk will flare brilliantly in visible and ultraviolet radiation.

If the giant star leaves behind a neutron star or a black hole instead of a white dwarf, an X-ray binary may form. In this case, the matter transferred from the main-sequence star will become extremely hot. When this matter strikes the surface of the neutron star or is pulled into the black hole, it will emit X rays.

In a third case, the red giant becomes a white dwarf, and the main-sequence star becomes a red giant. When enough gas from the giant accumulates on the dwarf's surface, gas nuclei will fuse violently in a flash called a nova. In some cases, so much gas will accumulate that its weight will cause the dwarf to collapse. Almost instantly, the dwarf's carbon will fuse, and the entire dwarf will explode in a Type I supernova. This kind of explosion is so bright that it can outshine an entire galaxy for a few months.

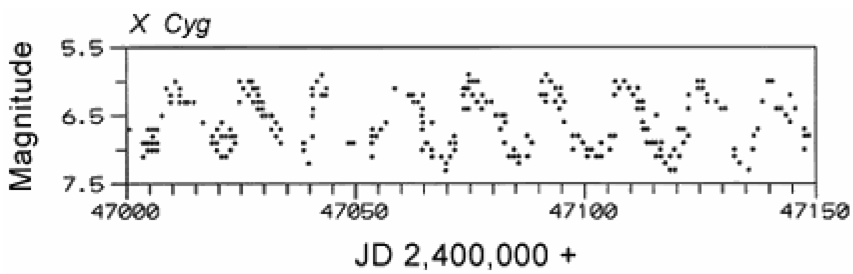
Variable Stars

Stars appear to shine with a constant light; however, thousands of stars vary in brightness. The brightness that a star appears to have (apparent magnitude) from our perspective here on Earth depends upon its distance from Earth and its actual intrinsic brightness (absolute magnitude.)

The behavior of stars that vary in magnitude (brightness) - known as variable stars - can be studied by measuring their changes in brightness over time and plotting the changes on a graph called a light curve. Amateur astronomers around the world observe variable stars and assist professional astronomers by sending their data to variable star organizations, such as the American Association of Variable Star Observers (AAVSO) in Cambridge, Massachusetts. The behavior of some variable stars can be observed with the unaided eye or binoculars. Measuring and recording the changes in apparent magnitude and drawing the resulting light curves will allow you to begin to unravel the stories of the often turbulent and always exciting lives of variable stars. The collection and study of variable star data requires the ability to estimate the apparent magnitudes of stars.

Variable stars are stars that vary in brightness, or magnitude. There are many different types of variable stars. One group of variable stars is the pulsating variables. These stars expand and contract in a repeating cycle of size changes. The change in size can be observed as a change in apparent brightness (apparent magnitude.) Cepheid variables are one type of pulsating variable stars. Cepheids have a repeating cycle of change that is periodic - as regular as the beating of a heart. Observations of the changes in apparent magnitude of variable stars - including Cepheids - are plotted as the apparent magnitude versus time, usually in Julian Date (JD). The resulting graph is called a light curve.

The light curve for the Cepheid variable star X Cyg (located in the constellation Cygnus) is shown below. Each data point represents one observation. Once many observations have been plotted, important information can be obtained from the resulting pattern of changing magnitudes. The period for X Cyg is the amount of time it takes for the star to go through one complete cycle from maximum magnitude (brightness), through minimum magnitude (dimmest), and back to maximum magnitude (brightness.)

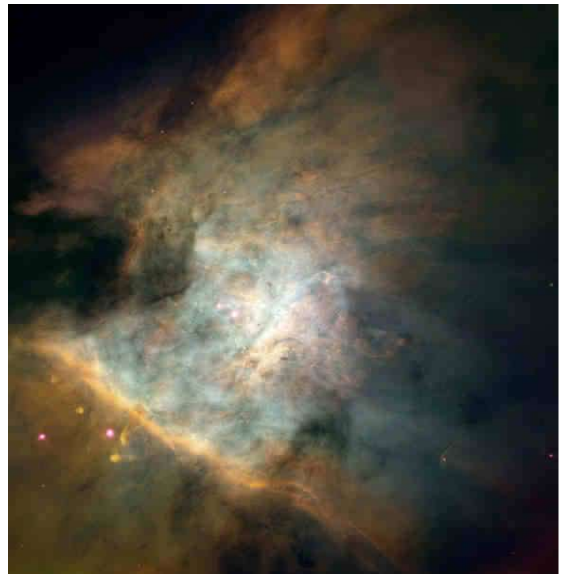


Light curve for the Cepheid variable star X Cyg.

Analysis of the light curve for X Cyg shows that the magnitude ranges from an average maximum magnitude of 6.0 to an average minimum magnitude of 7.0 with a period of approximately 16 days. X Cyg exhibits periodic behavior - it is a Cepheid variable star with a predictable cycle of changing magnitudes, a stellar heart that beats once every 16 days.

The Constellations

A constellation (KON stuh LAY shuhn) is a group of stars visible within a particular region of the night sky. The word constellation also refers to the region in which a specific group of stars appears. Astronomers have divided the sky into 88 areas, or constellations. The ancient Greeks, Romans, and people of various other early civilizations observed groups of stars in the northern two-thirds of the sky. They named these groups of stars after animals and mythological characters.



For example, the constellation Leo was named for a lion, Pisces for two fish, and Taurus for a bull. The constellations Andromeda, Cassiopeia, Orion, and Perseus are named for heroines and heroes in Greek mythology.

Between the early 1400's and the mid-1700's, European navigators explored the Southern Hemisphere and observed many constellations in the southernmost third of the sky. Mapmakers and explorers named these star groups for scientific instruments and other things as well as for animals. For example, the constellation Telescopium was named for the telescope. Musca was named for the fly, and Tucana for the toucan, a large-billed bird of Central and South America.

Some well-known groups of stars form only part of a constellation. Such smaller groups are called asterisms. For example, the Big Dipper is an asterism that lies in the constellation Ursa Major (Great Bear).

Some constellations can be seen only during certain seasons due to the earth's annual revolution around the sun. The part of the sky visible at night at a particular place gradually changes as the earth moves around the sun. Also, observers at different latitudes see different parts of the sky. An observer at the equator can view all the constellations during the course of a year, but an observer at the North or the South Pole can see only a single hemisphere of constellations.

The random arrangement of the stars visible to the naked eye has remained essentially unchanged since the time of the first written records. One of the earliest complete lists we have was compiled in about 120 BC by the Greek astronomer Hipparchus, and all the stars that he described can be found, with the same brightness and in practically the same place, in our skies today.

The whole sky has been arbitrarily divided into eighty-eight areas, which differ greatly in size and shape. Each area is a "constellation," or group of stars, and was thought to represent a mythical or semi-mythical being. Over half the constellations were recognized and mentioned by Hipparchus (and by Ptolemy, whose star catalogue came down to us through the Moslem scholars as the "Almagest"). The remaining constellations lie in the Southern Hemisphere and were not named until the sixteenth and seventeenth centuries.

Few of the groups of stars that form constellations look much like the objects they represent. Much imagination is needed to see the "pictures" seen by those gazing at the skies so many years ago.

As the earth moves around the sun in its yearly cycle, the sun appears to "move" through the constellations. The path is known as the ecliptic. The constellations along the ecliptic were given special significance, and became known as the "signs of the zodiac".

In antiquity the beginning of the year was reckoned from the start of spring, called the vernal equinox. The vernal equinox and the autumnal equinox are the two days each year when day and night are equal in length. The constellation through which the sun is passing at the time of vernal equinox changes slowly with the centuries, and therefore the stars associated with the season of spring also change slowly. In the time of Hipparchus the sun was in Aries at the time of vernal equinox; today it is in Pisces, but will soon move into Aquarius (hence we are now at the "dawning of the age of Aquarius"). From tablets found in the Euphrates valley, we find they started the year when the sun was in the constellation Taurus, the "Bull in Front". If the sun was in Taurus at vernal equinox when the constellation was named, the date would have been about 2450 BC!

Names of the Constellations

Andromeda - Andromeda
Antlia - The Air Pump
Apus - The Bird of Paradise
Aquarius - The Water-Carrier

Aquila - The Eagle
Ara -The Altar
Aries - The Ram
Auriga - The Charioteer
Bootes - The Herdsman
Caelum - The Graving Tool
Camelopardalis - The Giraffe
Cancer - The Crab
Canes Venatici - The Hunting Dogs
Canis Major - The Great Dog
Canis Mino - The Little Dog
Capricornus - The Goat
Carina - The Keel
Cassiopeia - Cassiopeia
Centaurus - The Centaur
Cepheus - Cepheus
Cetus -The Whale
Chamaeleon - The Chameleon
Circinus - The Pair of Compasses
Columba - The Dove
Coma Berenices - Berenice's Hair
Corona Australis - The Sourthern Crown
Corona Borealis - The Northern Crown
Corvus - The Crow
Crater -The Goblet
Crux - The Cross
Cygnus - The Swan
Delphinus - The Dolphin
Dorado - The Swordfish
Draco - The Dragon
Equuleus Equ The Little Horse
Eridanus - The River Eridanus
Fornax - The Furnace
Gemini - The Twins
Grus - The Crane
Hercules - Hercules
Horologium - The Clock
Hydra - The Sea-Serpent
Hydrus - The Water-Snake
Indus - The Indian
Lacerta -The Lizard
Leo - The Lion
Leo Minor - The Little Lion
Lepus - The Hare

Libra - The Scales
Lupus - The Wolf
Lynx - The Lynx
Lyra - The Lyre
Mensa - The Table (Mountain)
Microscopium - The Microscope
Monoceros - The Unicorn
Musca - The Fly
Norma - The Ruler
Octans - The Octant
Ophiuchus - The Serpent-Bearer
Orion - Orion, the Hunter
Pavo P- The Peacock
Pegasus -Pegagus, the Winged Horse
Perseus - Perseus
Phoenix - The Phoenix
Pictor - The Easel
Pisces - The Fishes
Piscis Austrinus - The Southern Fish
Puppis - The Fishes
Pyxis - The Mariner's Compass
Reticulum - The Net
Sagitta - The Arrow
Sagittarius - The Archer
Scorpio - The Scorpion
Sculptor - The Sculptor's Tools
Scutum - The Shield
Serpens - The Serpent
Sextans - The Sextant
Taurus - The Bull
Telescopium - The Telescope
Triangulum - The Triangle
Triangulum Australe - The Southern Triangle
Tucana - The Toucan
Ursa Major - The Great Bear (Big Dipper)
Ursa Minor - The Little Bear (Little Dipper)
Vela - The Sails
Virgo - The Virgin
Volans - The Flying Fish
Vulpecula - The Fox

Constellations Sorted by Month

This is a list of all 88 constellations split up into the months when they are best seen in the sky. The months listed assume that you are looking at the sky at 9:00 PM. For every hour later than 9:00, add half of a month. For every hour before 9:00, subtract half a month. The constellations are typically visible for more than just one month, depending on where you are on the Earth. If you need to know exactly when a constellation is visible, check in a star atlas or on a planisphere.

January

Caelum
Dorado
Mensa
Orion
Reticulum
Taurus

February

Auriga
Camelopardalis
Canis Major
Columba
Gemini
Lepus
Monoceros
Pictor

March

Cancer
Canis Minor
Carina
Lynx
Puppis
Pyxis
Vela
Volans

April

Antlia
Chamaeleon
Crater
Hydra
Leo
Leo Minor
Sextans
Ursa Major

May

Canes Venatici
Centaurus
Coma Berenices
Corvus
Crux
Musca
Virgo

June

Boötes
Circinus
Libra
Lupus
Ursa Minor

July

Apus
Ara
Corona Borealis
Draco
Hercules
Norma
Ophiuchus
Scorpius
Serpens
Triangulum Australe

August

Corona Austrina
Lyra
Sagittarius
Scutum
Telescopium

September

Aquila
Capricornus
Cygnus
Delphinus
Equuleus
Indus
Microscopium
Pavo
Sagitta
Vulpecula

October

Aquarius
Cepheus
Grus
Lacerta
Octans
Pegasus
Piscis Austrinus

November

Andromeda
Cassiopeia
Phoenix
Pisces
Sculptor
Tucana

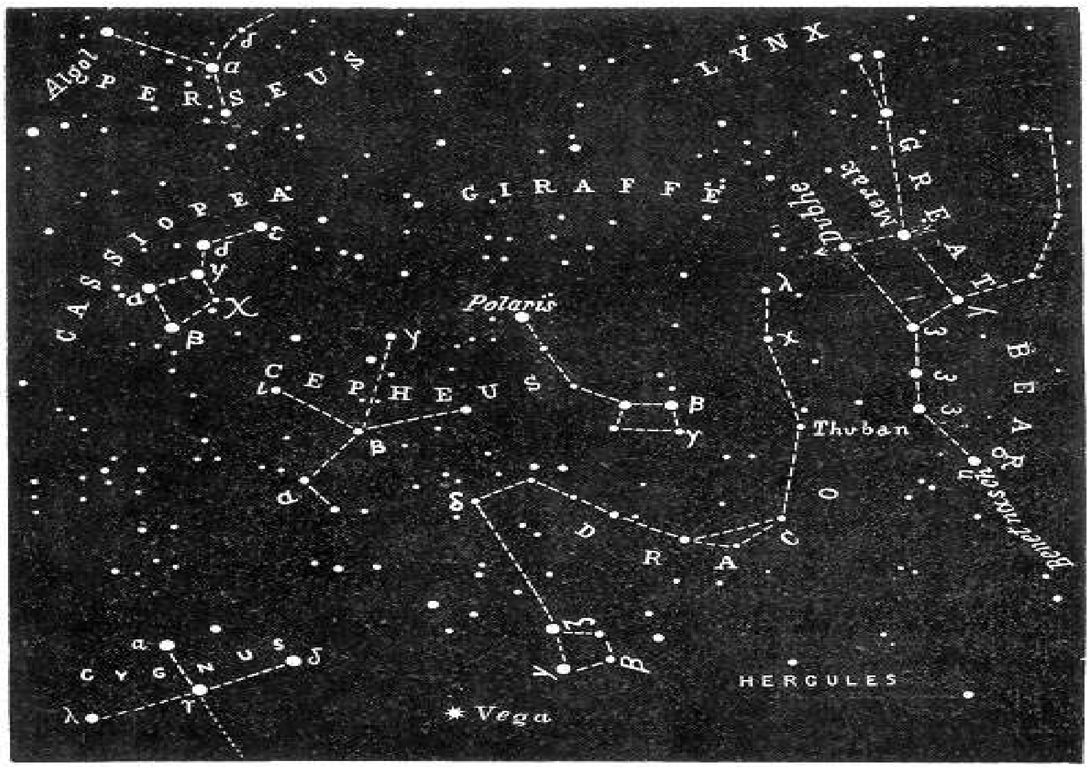
December

Aries

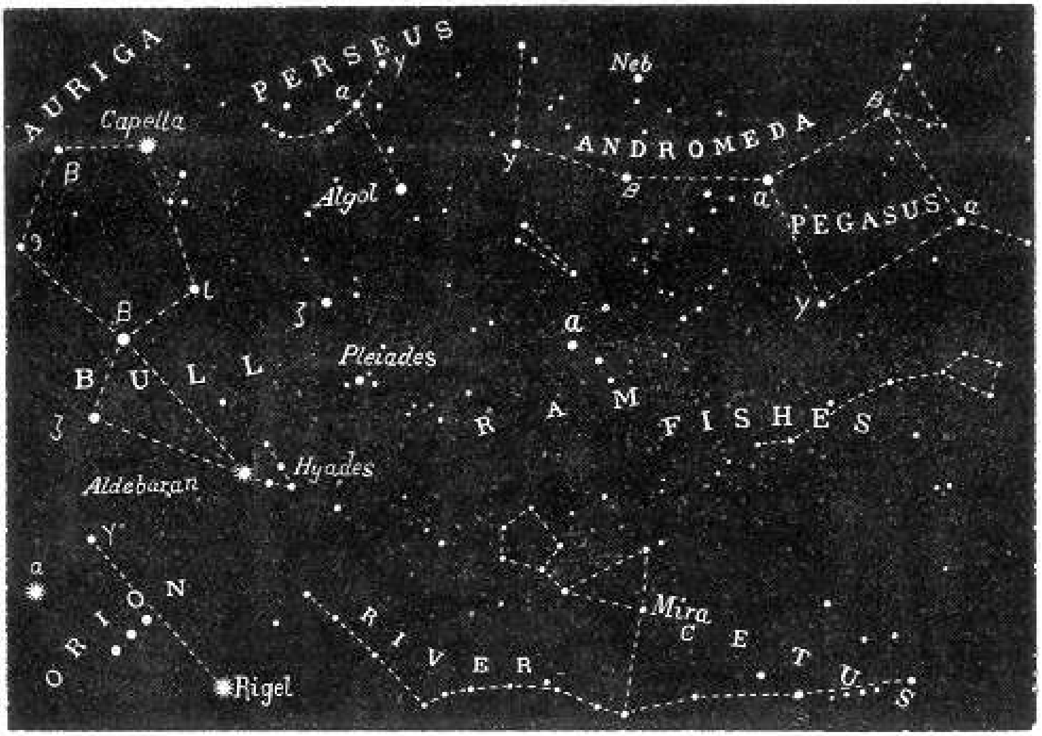
Cetus
Eridanus
Fornax
Horologium
Hydrus
Perseus
Triangulum

FINDING THE STARS IN THE SKY

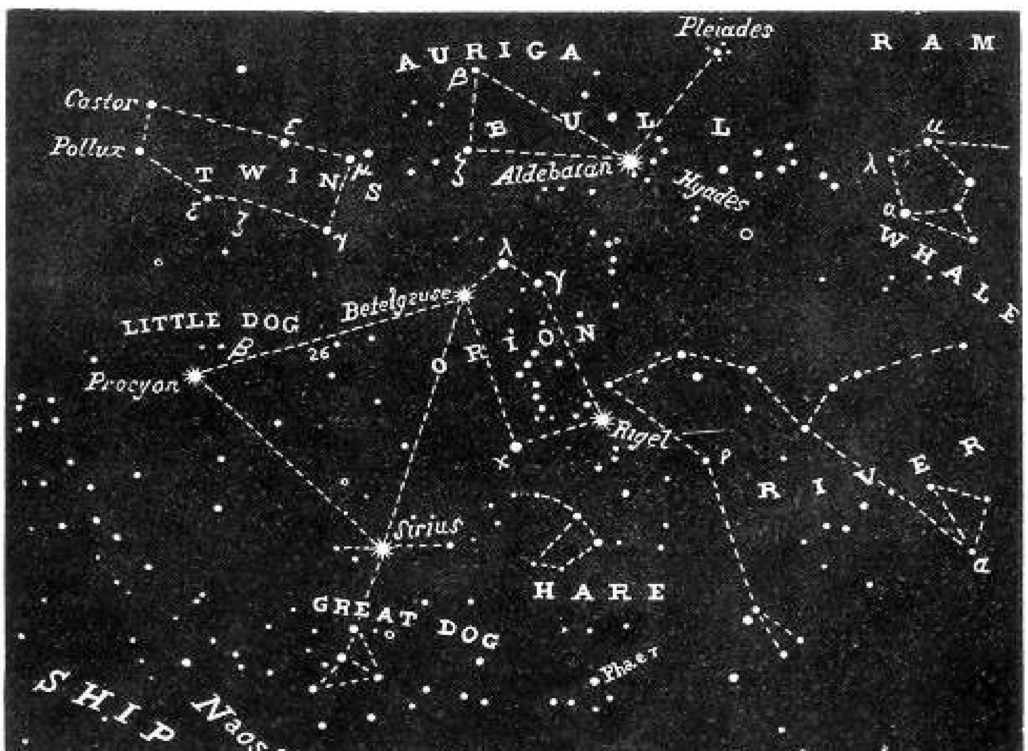
Detach any of the following maps, appropriate to the time of year, hold it between you and a flashlight outdoors, and you have an exact miniature of the sky. Or, better, cut squares of suitable sizes from the four sides of a box; put a map over each aperture; provide for ventilation, and place the box over a flashlight outdoors. Use binoculars to find the smaller stars, if accessible.



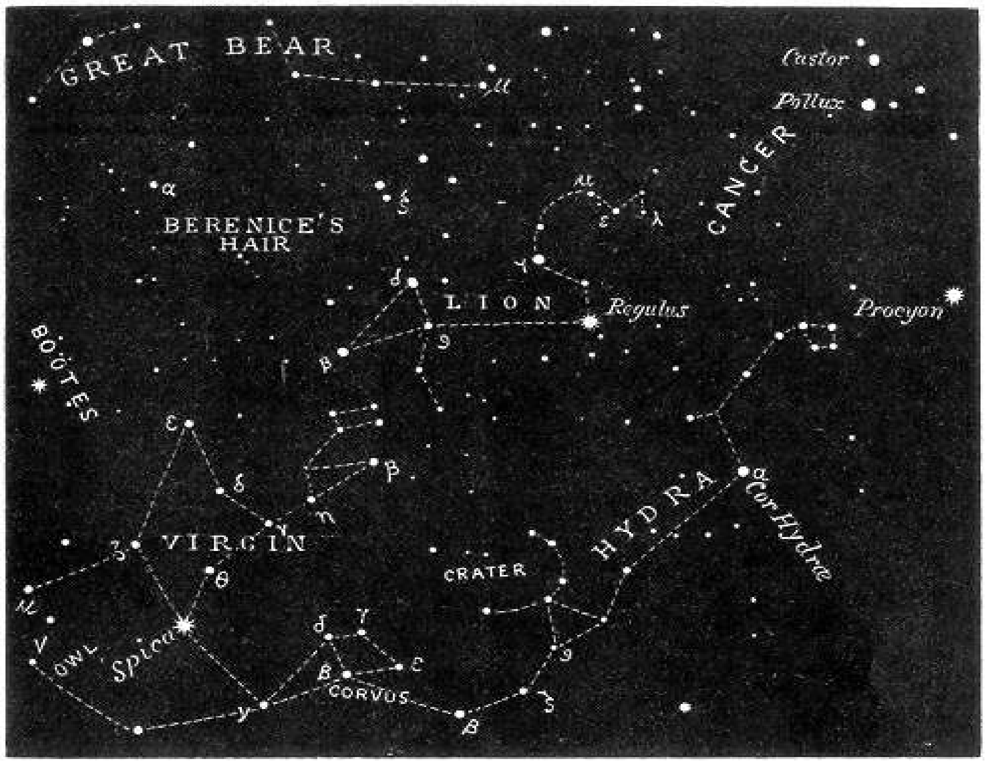
Circumpolar Constellations. Always visible. In this position.—January 20th, at 10 o'clock; February 4th, at 9 o'clock; and February 19th, at 8 o'clock.



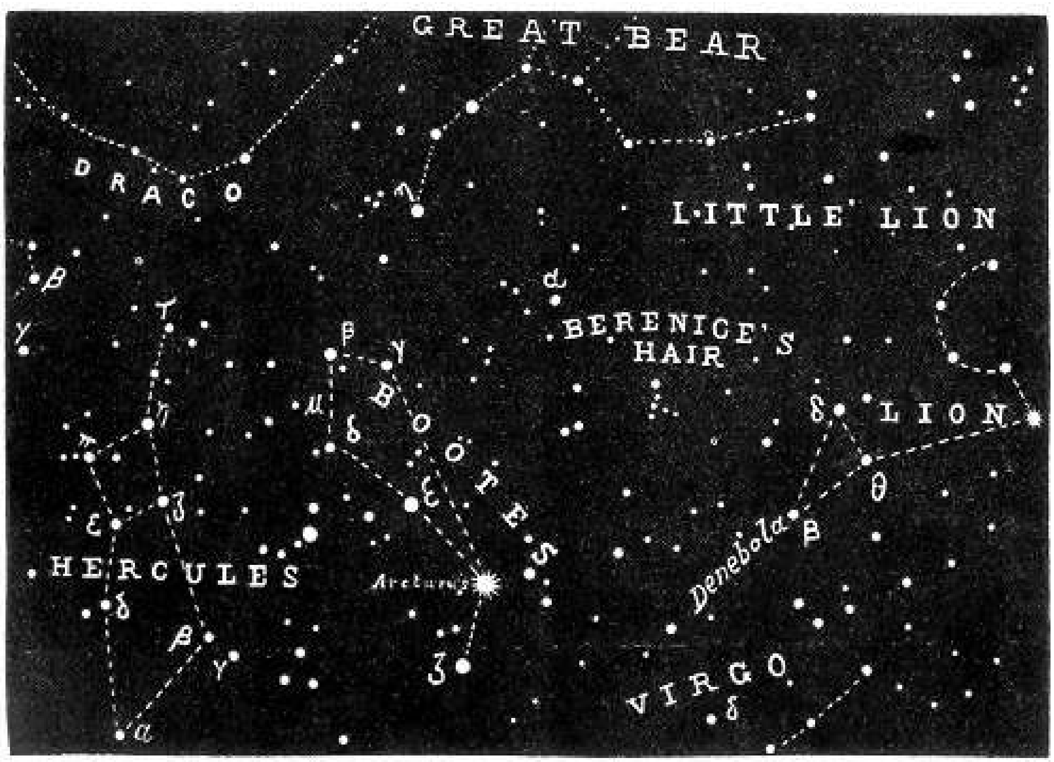
Algol is on the Meridian, 51° South of Pole.—At 10 o'clock, December 7th; 9 o'clock, December 22d; 8 o'clock, January 5th.



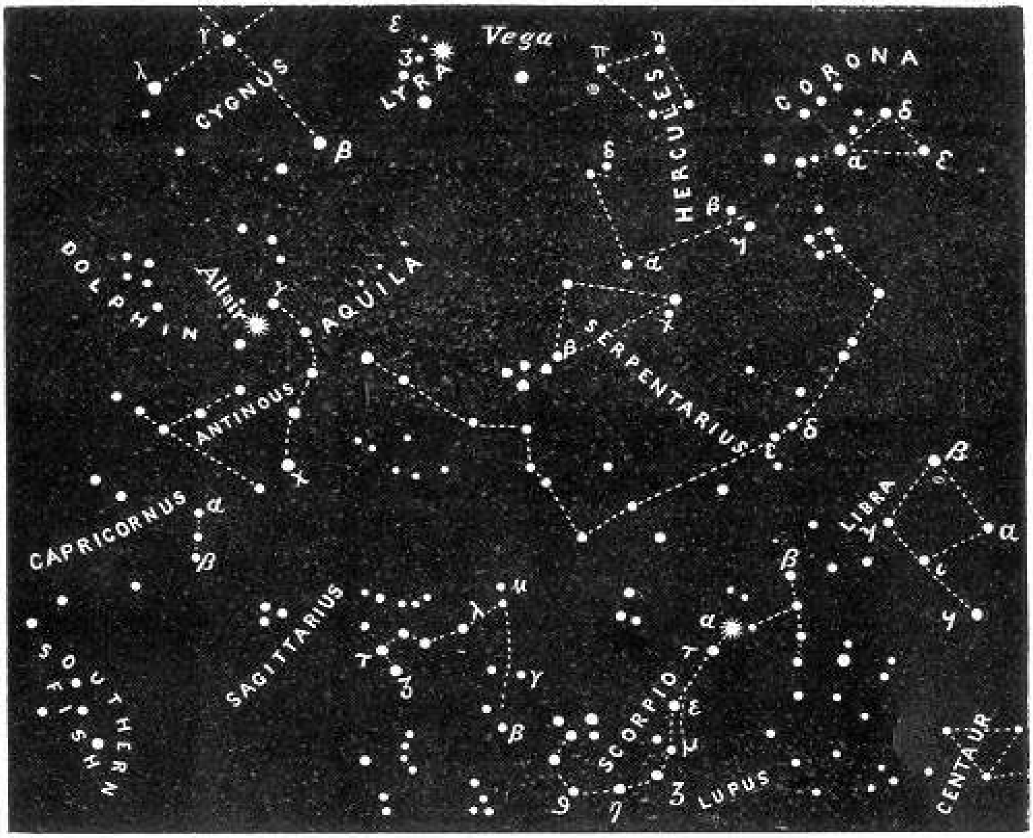
Capella (45° from Pole) and Rigel (100°) are on the Meridian at 8 o'clock February 7th, 9 o'clock January 22d, and at 10 o'clock January 7th.



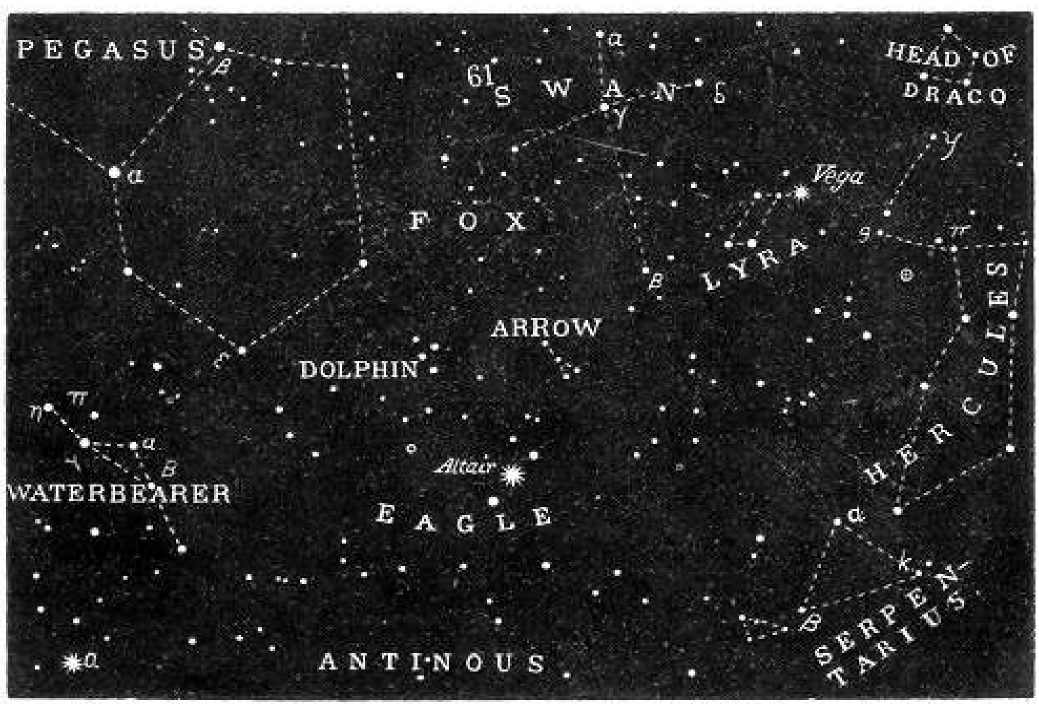
Regulus comes on the Meridian, 79° south from the Pole, at 10 o'clock March 23d, 9 o'clock April 8th, and at 8 o'clock April 23d



Arcturus comes to the Meridian, 70° from the Pole, at 10 o'clock May 25th, 9 o'clock June 9th, and at 8 o'clock June 25th



Altair comes to the Meridian, 82° from the Pole, at 10 o'clock P.M. August 18th, at 9 o'clock September 2d, and at 8 o'clock September 18th.



Fomalhaut comes to the Meridian, only 17° from the horizon, at 8 o'clock November 4th