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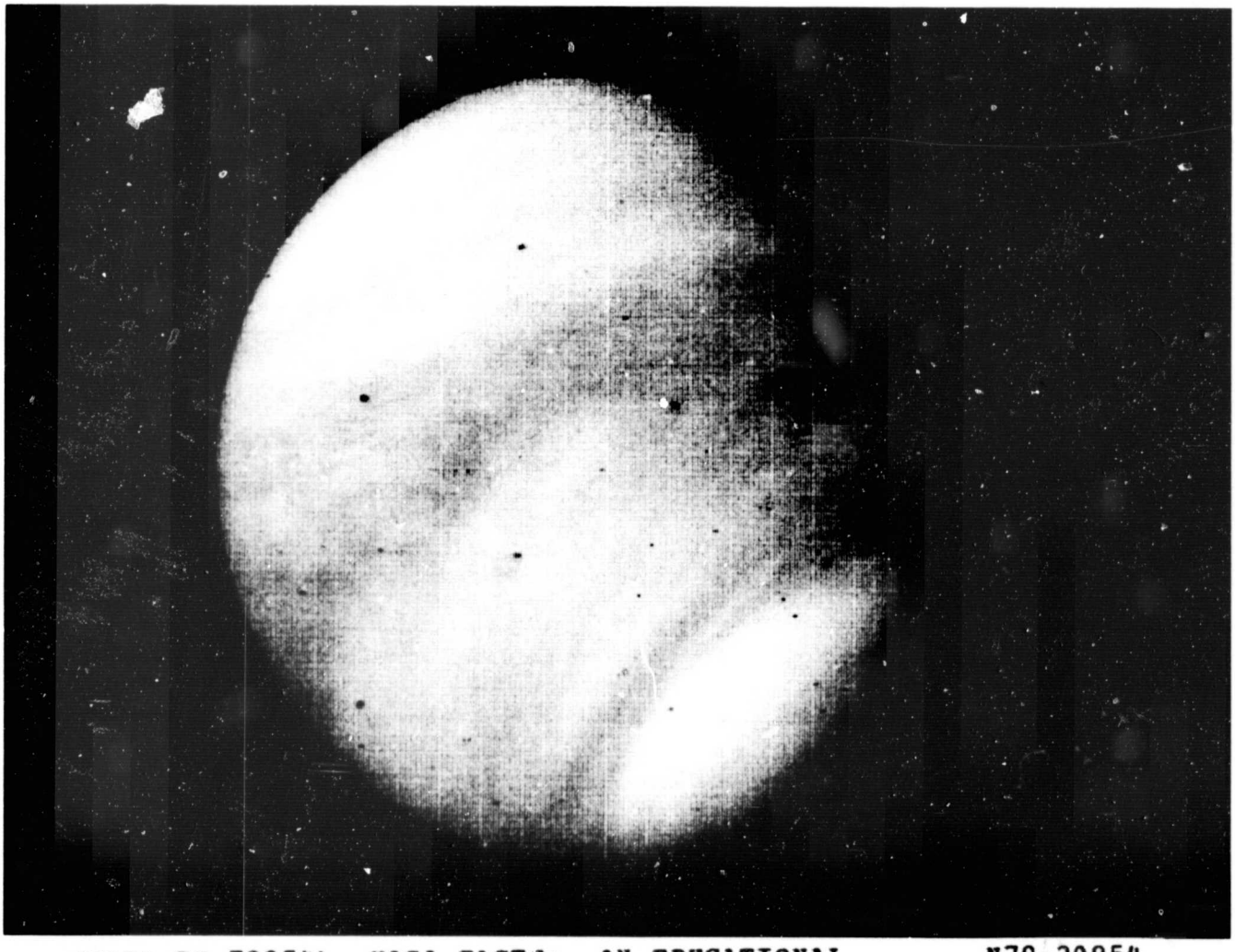
The Planet Venus

One of a series of NASA Facts about the exploration of Venus.

In 1978 NASA will send two spacecraft to Earth's nearest planetary neighbor, Venus. This is the Pioneer-Venus mission. One spacecraft will orbit the planet and send scientific information back to Earth for months. The other will carry four probes that will detach and plunge into the atmosphere of Venus to tell us about its meteorology, its composition, and its complex chemistry, but they are not designed to survive after impact.

Venus is a fascinating planet because it is



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almost a twin of Earth but has developed quite differently so that our type of life cannot live on its surface. Scientists want to find out why it developed the way it did, and in so doing, gain greater insight into the nature of the processes that have molded our Earth and brought it to the conditions of today.

Venus as a Member of the Solar System

After the Sun and the Moon, Venus is the brightest object in the sky. If you know where to look you can sometimes see Venus in broad daylight. Like other planets Venus appears to move through the constellations of the Zodiac, but it is never seen far from the Sun because it is an "inferior" planet. That is, it travels along an orbit within that of the Earth. Venus takes only 225 days to go completely around the Sun. The position of Venus east or west of the Sun is referred to as an elongation. At eastern elongation you can see it as a bright, star-like object in the evening sky. At western elongation you have to look for it rising before the Sun in the early morning sky (Figure 1).

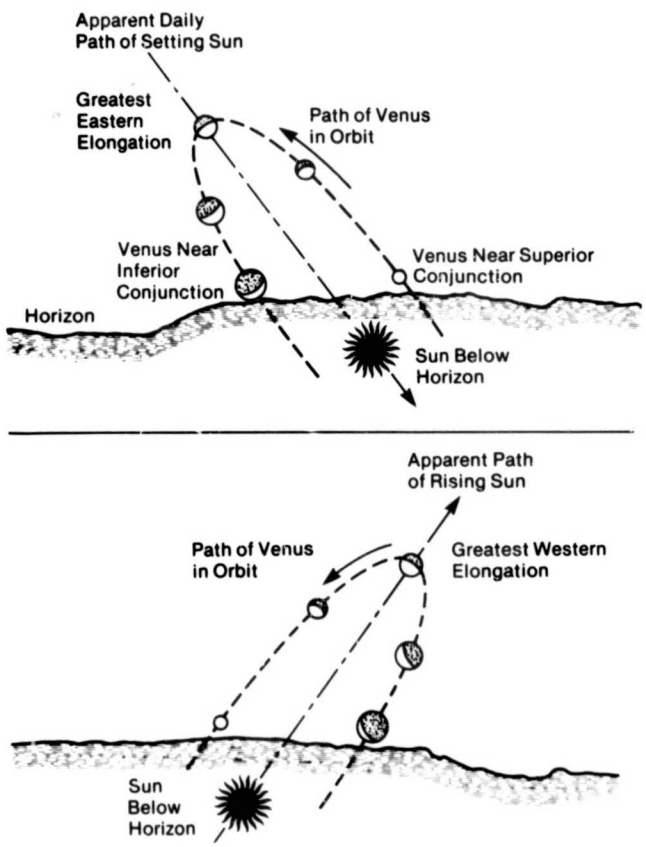


Figure 1. Venus moves from superior conjunction to the east of the Sun and thus appears as an evening star. As it progresses around its orbit, it passes through inferior conjunction between Earth and Sun and then becomes a morning star, rising before the Sun.

When Venus passes between Earth and Sun, and thus comes closest to the Earth, it passes through what astronomers call inferior conjunction. On the far side of the Sun it passes through superior conjunction (see Figure 2). The positions of greatest elongation correspond to quadratures on the orbit.

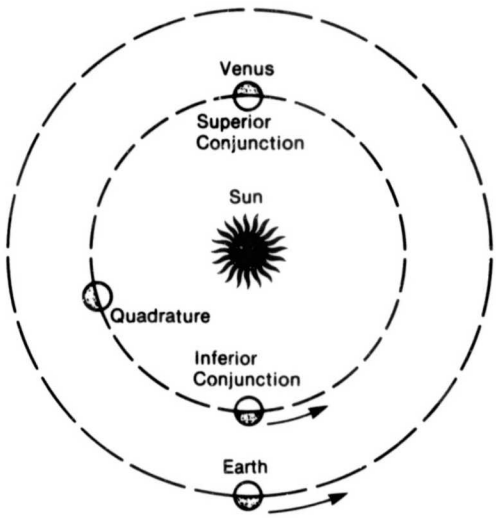


Figure 2. The orbits of Venus and Earth show the positions of the conjunctions.

Venus as a Planet

The mass, diameter, and density of Venus are all only slightly less than those of the Earth. But its surface is hotter, its atmosphere much denser, and its rotations much slower than those of the Earth. Venus is one of the three planets of the solar system that do not have satellites; the others are Mercury and Pluto. Also Venus does not have a significant magnetic field.

The diameter of Venus is 12,100 km (7519 mi) and its average density is 5.25 times that of water. This high density may imply that Venus has a core of nickel and iron like the Earth.

The surface of Venus cannot be observed visually from Earth because Venus is shrouded in a thick blanket of clouds. However, radar waves from Earth stations penetrate to the surface and astronomers have used them to map the surface of Venus. In addition, the surface emits radio waves—microwaves—which penetrate the clouds and can be received on Earth. Astronomers use these radio waves to estimate the temperature of the planet's surface.

In the early 1960's when these measurements were first made, astronomers were surprised to discover that the surface of Venus is extremely hot. The microwaves carry the message that it is about 430°C which is hot enough to melt zinc. They also told us that the temperature is the same both day and night on the surface of Venus.

The surface temperature of Venus is much higher than that of the Earth. This difference is attributed to the dense atmosphere of Venus which traps incoming solar radiation and prevents

Figure 3. In visible light Venus is a featureless, bright, yellowish globe. In ultraviolet light the clouds of Venus have prominent patterns as shown in this mosaic of pictures taken by NASA's spacecraft, Mariner 10, as it flew by Venus on the way to Mercury.

heat from being reradiated into space. This is termed the "greenhouse effect."

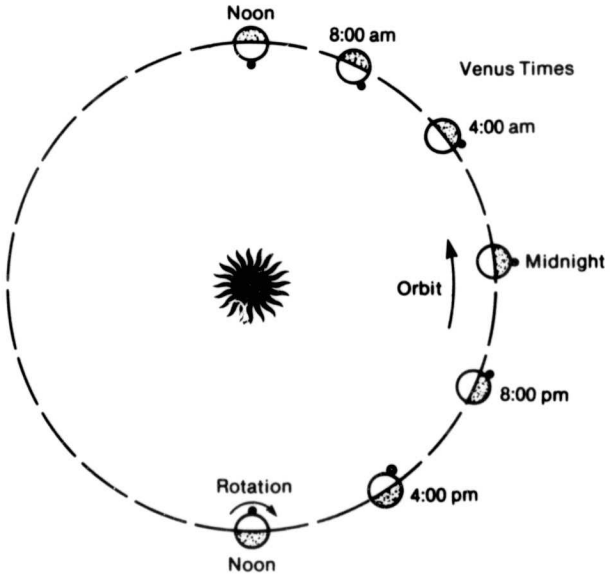
A telescope reveals no details in the yellowish clouds of Venus. However, if these clouds are photographed in ultraviolet light, dark shadings can be seen that rotate in a period of about 4 days. These shadings have also been seen more clearly in ultraviolet pictures of Venus taken from a passing spacecraft (Figure 3).

But the planet itself rotates much more slowly than its cloud tops. Again the discovery was made by radio waves. Transmitted from the Earth by a big antenna, these waves are reflected by Venus. Radar astronomers can tell from the form of the radio echo that Venus rotates once in 243.1 days, in a direction opposite to the rotation of the Earth. This is called a retrograde direction. A day (the time from one sunrise to the next) on Venus lasts about 117 Earth days (Figure 4).

Another peculiar fact about the rotation of Venus is that it seems to be linked to the Earth. Each time Venus passes closest to the Earth at inferior conjunction, the same face of Venus is turned towards the Earth. Most astonomers believe this is just a coincidence, but it may not be.

Astronomers do not know why Venus rotates so slowly. The other planets (except Mercury) rotate quickly on their axes. Mercury has been slowed by tidal friction because of its closeness to the Sun; but Venus is not only rotating slowly, it is also rotating in the "wrong" direction. The Sun could not have caused this. One possibility, proposed some years ago, is that Venus once had a big satellite that revolved around it in the retrograde direction. This satellite crashed into Venus and stopped the planet's rotation, or perhaps even pushed it a little into rotating the opposite way.

Astronomers looked at the spectrum of light reflected from the clouds of Venus and were able to find that its atmosphere contains much (97%)



Axial Rotation: 243.1 Earth days

Orbital period: 225 Earth days (= Venus year)

Noon to Noon: 116.8 Earth days (= Venus day)

Venus year: 1.93 Venus days

Figure 4. A combination of retrograde rotation about its axis in 243.1 days and orbital revolution about the Sun in 225 days make a day on Venus 116.8 Earth days long, as shown in this diagram.

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carbon dioxide. This again is a contrast to Earth which only has a small amount (0.03%) of carbon dioxide in its atmosphere. The reason there is so much carbon dioxide in the atmosphere of Venus is thought to be because Venus is a dry planet. The presence of oceans of water on Earth allowed Earth's early atmosphere of carbon dioxide to react with the rocks and form carbonates. Today, most of Earth's carbon dioxide is bound up as carbonates in rocks. Also living things on Earth used carbon dioxide from the atmosphere to provide carbon for their bodies. Oxygen was released by plants to form Earth's oxygen-rich atmosphere of today.

Another big difference between Earth and Venus, as mentioned earlier, is that Venus does not have a magnetic field of any significance. As a consequence its atmosphere has no protection from the blizzard of high-energy particles —protons and electrons—known as the solar wind. These particles are held away from the Earth by our magnetic field. But they speed directly into the upper atmosphere of Venus.

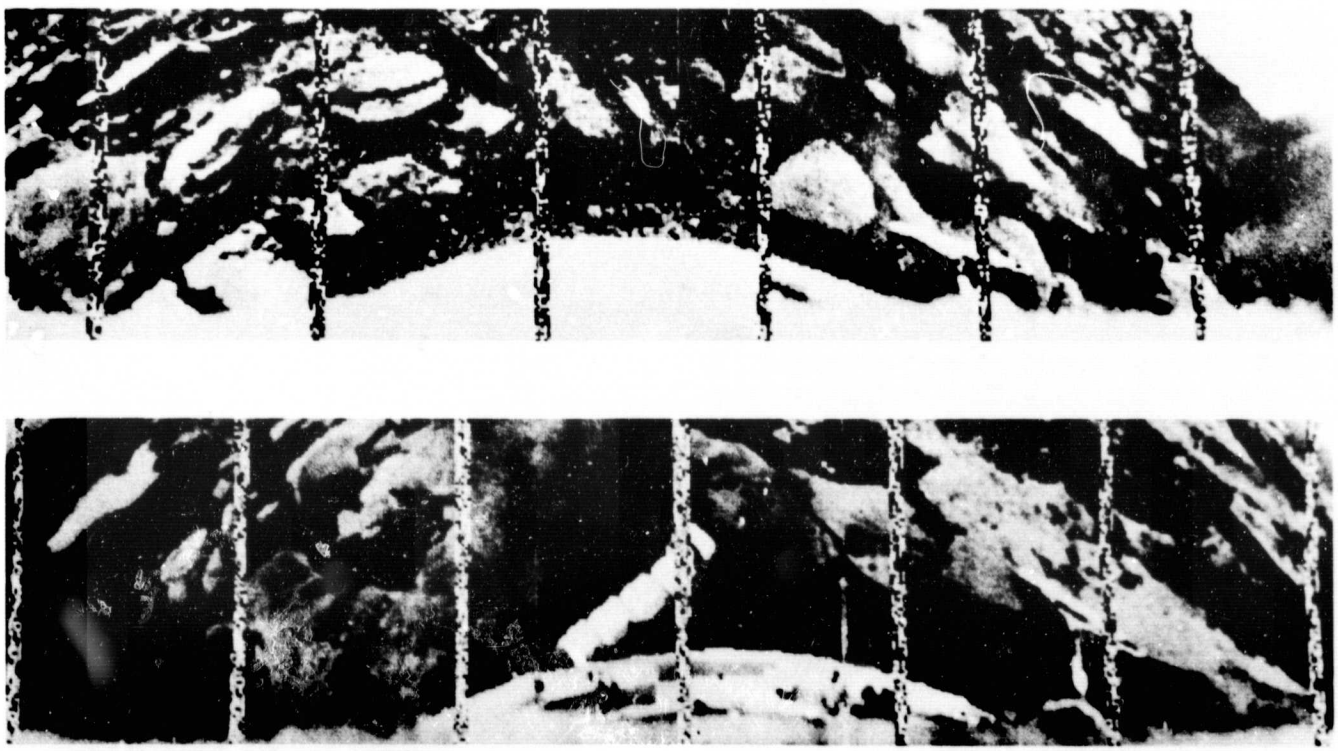
The Surface of Venus

Details on the surface of Venus were virtually unknown until two Soviet Venera spacecraft landed on it in 1975 and returned pictures. Earlier speculations had ranged from steaming swamps to dusty deserts, from carbonated seas to oceans of bubbling petroleum. All were wrong, though the desert concept seems closest to what is now known. Photographs from the Venera spacecraft (Figure 5) revealed a dry rocky surface fractured and changed by unknown processes. There are rocks of many different kinds and a dark soil. The two spacecraft landed about 2000 km (1200 mi) from each other. One landed on an ancient plateau or plains area. At this site there are rocky elevations interspersed with a relatively dark, fine-grained soil. This soil seems to have resulted from a weathering of the rocks, possibly by a chemical action. The rocky outcrops are generally smooth on a large scale, with their edges blunted and rounded. The dark soil fills some of the cavities in the rocks. By contrast the other Venera landed at a site where there are rocks which look younger and less weathered, with not much evidence of soil between them.

Measurements made by the Russian spacecraft showed that all these rocks on Venus have a density and radioactive content similar to terrestrial basaltic rocks.

In 1962, craters were discovered on radar maps of the planet (Figure 6). Subsequently, radar astronomers found evidence of large lava flows, great circular basins like those of the Moon, and even chasms and volcanoes like those on Mars. Generally, however, the surface of Venus is not so rugged as Earth and Mars. Radar measurements of altitude variation on Venus amount to only

Figure 5. The first pictures of the surface of Venus were returned to Earth by two Soviet Venera spacecraft that landed on Venus in 1975. The top picture is from Venera 9 and the bottom from Venera 10. They show rocky terrains which are surprisingly different at the two sites, the Venera 10 site showing evidence of much greater age, inferred from the weathered nature of the rocks.



about 5 km (3 mi) compared with Earth's range of 20 km (12 mi) between the top of Mt. Everest and the bottom of the Marianas Trench, and Mars' range of 30 km (20 mi) between the top of Olympus Mons and the bottom of the Hellas basin.

The existence of craters and other features on the surface of Venus suggests that the planet had been subjected to a bombardment from space early in its history, just as the other inner planets of the solar system were bombarded, and that afterwards there were volcanic activities, lava flows, and possibly some mountain building. The evolution of Venus may have progressed to an even more Earth-like state than that of Mars. But the absence of water on Venus prevented it from becoming like the Earth is today.

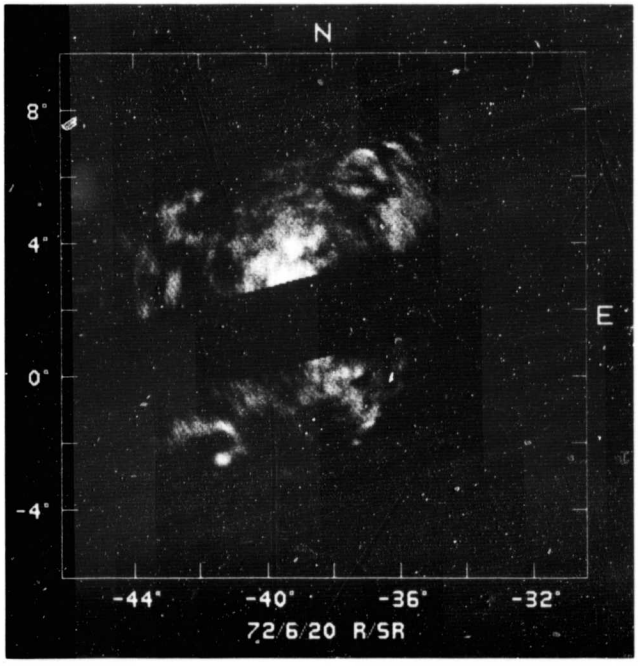


Figure 6. Radar scanning of the surface of Venus using the Deep Space Antennas of NASA's network, revealed craters as shown in this picture of an equatorial region. The dark band across the picture covers an area for which radar data were not obtained.

The Atmosphere of Venus

The atmosphere of Venus (Figure 7) was discovered by a Russian astronomer in the 16th century when the planet was seen to cross the face of the Sun in transit. The black disc of Venus silhouetted against the Sun was distorted by the planet's atmosphere when close to the edge of the Sun. Also, other astronomers saw the atmosphere extending the arms of the crescent Venus.

The brilliant clouds of Venus were at one time thought to be clouds of water droplets. Other speculations included dust, exotic compounds of chlorine and fluorine, and ice crystals. The clouds are pale yellow in color and reflect about 85% of the sunlight falling upon them. Their true nature was not discovered until a few years ago, when astronomers used a variety of observations to show that the clouds are composed of droplets of sulfuric acid.

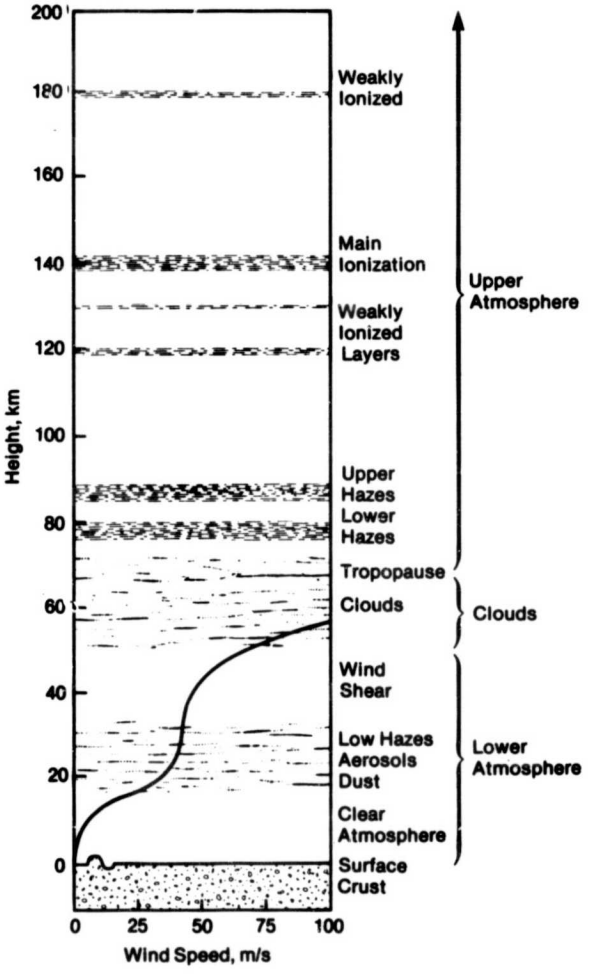


Figure 7. Space probes and ground-based observations have established these details of the structure of the Venusian atmosphere. The curve across the lower part of the sketch shows the wind speed at altitudes measured by one of the Soviet spacecraft.

The general composition of the atmosphere was not known until 1932 when carbon dioxide was discovered by the use of a spectroscope to analyze the light from the planet. Space probes have confirmed that the atmosphere of Venus is about 97% carbon dioxide, and that it is almost 100 times as dense as Earth's atmosphere.

The atmospheres of Earth and Venus probably originated from radioactive heating of both planets. As the rocks became hot, lightweight

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gases such as carbon dioxide and water "boiled off" (outgassed) from the mantle and crust. If Venus went through as much outgassing as the Earth, it would be expected to have had originally an atmosphere consisting of carbon dioxide in an amount 100 times the amount of all Earth's present-day atmosphere, and of water equivalent to the amount in the Earth's oceans.

The Earth has held water in its oceans because its surface is not hot enough to evaporate all the water into its atmosphere, which has a region of low temperature (a cold trap) in the stratosphere that prevents water vapor from rising to a height at which solar ultraviolet radiation could break water molecules into oxygen and hydrogen.

On Venus, which is closer to the Sun, the planet was probably hot enough originally for all the water to evaporate into the atmosphere. In such a water-saturated, hot atmosphere there could be no cold trap, and water would break down into oxygen and hydrogen. The hydrogen would have leaked off into space. The oxygen might have reacted with surface rocks to oxidize them, but this is only speculation.

Another theory is that Venus was not formed from the same basic materials as the Earth and did not have much water to begin with.

Whichever way it happened, Venus is very short of water today. Its atmosphere is extremely dry, especially above the clouds.

Another effect of the dense atmosphere of carbon dioxide is to trap incoming solar radiation and prevent heat radiation from the surface and the lower atmosphere from escaping back into space. The surface temperature of 480°C (900°F) permits very active chemical reactions between the atmosphere and the surface materials, and many substances that on Earth would be bound in the rocks are probably released into the atmosphere of Venus. These include chlorine and fluorine.

Like on Earth, sulfur is probably released into the atmosphere of Venus. This sulfur rises high into the Venusian atmosphere where it combines with water and oxygen to produce sulfuric acid. It is a haze of droplets of sulfuric acid, more concentrated than the acid in an automobile's battery, that forms the very deep clouds of Venus. These hazy clouds are not thickly opaque like rain clouds of Earth, but they have extremely deep layers. Their tops are 80 km (50 mi) above the surface of Venus, and their bottoms are about 50 km (30 mi) above the hot surface of the planet.

Above and below the sulfuric acid clouds are other thinner haze layers of unknown composition. But there seems to be a clear region for about 20 km (12 mi) above the surface. Thus, while Earth's first 20 km are cloud filled, on Venus these first 20 km of atmosphere are clear. Venus' clouds and weather begin at the level of Earth's upper stratosphere.

Close to the surface of Venus there are only slight breezes, whereas at the top of the sulfuric acid clouds the winds reach 360 km/hr (220 mi/hr), comparable to Earth's jet streams. The high winds of Venus sweep around the planet and make it appear that the topmost regions of the clouds (visible in ultraviolet light as dark and light shadings) whirl around the planet in about 4 days.

There are also circulating motions within the atmosphere. Regions of rising gas are located along the equator where solar heat affects the atmosphere most. Other regions of descending gas are located toward the poles. The atmosphere is known to be in circulation because the temperature is virtually the same on the day and night sides and from equator to poles. Therefore the atmosphere of Venus must be constantly agitated like water coming to the boil in a saucepan.

Down close to the surface, thermal (heat) chemical reactions occur in the atmospheric gases and between the atmosphere and the surface rocks. Above the sulfuric acid clouds chemical reactions are controlled by the ultraviolet solar radiation; they are photochemical reactions. Within the droplets of the clouds other chemical reactions take place in a liquid phase. The chemistry of the atmosphere of Venus is thus extremely complex, and it is not yet thoroughly understood.

High above the clouds and the hazes is the upper atmosphere of Venus which changes into a region of mainly helium and hydrogen, called the exosphere, and then into interplanetary space. Incoming solar radiation affects the atoms and molecules of the upper atmospheric gases and ionizes them, making them electrically charged. This forms an ionosphere somewhat similar to Earth's ionosphere. Both ionospheres have layers. We use the layers in Earth's ionosphere to reflect certain frequencies of radio waves around the world for long-distance radio communications.

The layers of the ionosphere of Venus are not as intensely ionized as those of Earth's ionosphere, and are generally lower and thinner. Also the temperature of Venus' ionosphere is much less than that of Earth's ionosphere. So while Venus' lower atmosphere is hotter than that of the Earth, its upper atmosphere is cooler.

As already mentioned, because Venus does not have a magnetic field of any consequence, its upper atmosphere receives directly the solar wind of protons and electrons streaming from the Sun. This causes a sharp boundary for Venus'

ionosphere, at an altitude of only 350 to 500 km (200 to 300 mi) on the day side of the planet. On the night side, the ionosphere trails out behind the planet in a "tail" extending downwind into interplanetary space (Figure 8).

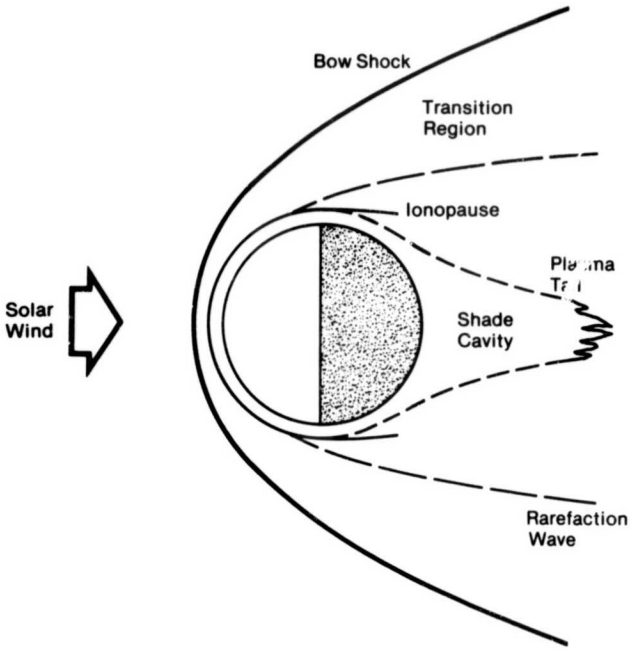

Figure 8. Because Venus has an insignificant magnetic field, it interacts differently than Earth with the solar wind, which penetrates very close to the planet as compared with the Earth. This sketch shows the bow shock where the solar wind is slowed down by the atmosphere of Venus. Behind the planet is a cavity and a plasma tail.

There are many unanswered questions about Venus which scientists hope will be answered by new information to be provided by NASA's Pioneer-Venus spacecraft. Such questions include:

What causes the weather on Venus?

Is it really a greenhouse effect that makes the planet so hot?

What causes the dark markings in the Venus clouds?

What are the various constituents of the Venus atmosphere?

How does the ionosphere interact with the solar wind?

How these and other questions about Venus might be answered by the Pioneer-Venus mission will be discussed in another fact sheet of this series.

Further Reading

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Student Projects

1. Planetary Orbits and Apparitions

You are given the following information:

Mean distance of Venus from the Sun is 107.5 million km. Mean distance of the Earth from the Sun is 149.6 million km. Period of Venus in its orbit around the Sun is 225 Earth days. Period of Earth in its orbit around the Sun is 365.25 Earth days.

If Venus was in inferior conjunction (see Figure 2) on April 6, 1977, work out when the next inferior conjunction will take place. Note that when Venus has made one circuit of the Sun, Earth has only completed part of a complete circuit.

A NASA Pioneer-Venus orbiter, launched toward Venus in May or June, will arrive in the vicinity of the planet in December. A probe spacecraft launched in August will also reach Venus in December. Is Venus a morning or an evening "star" at the time both spacecraft arrive there?

If Venus is brightest in the sky of Earth about 36 days before or after inferior conjunction, what date in December should the spacecraft arrive at Venus if Venus were to be its brightest as seen on Earth?

2. The Atmosphere of Venus

You are provided with information obtained from a probe that penetrates the atmosphere of Venus. This probe carries instruments to measure the speed of the wind and the temperature of the Venus atmosphere. While the wind speed instrument gave good data points all the way to

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the surface, the temperature measuring instrument failed at high temperature about 8 km above the surface. These are the data points:

Height km	Wind Speed m/s	Temperature °C
70	135	– 50
65	135	– 30
60	130	– 19
56	120	47
50	87	100
45	68	139
39	45	177
34	99	223
30	41	267
26	40	298
19	34	327
15	25	201
10	4	400
6	1	–
1	0	–

Make a graph showing wind speed and temperature plotted against height above the surface of Venus. Try to fit a smooth curve between your data points. Are there any wild points that do not fit? Do you think these are real or a fault of the instrument? If you reject these points do you get smooth curves? Can you extrapolate the temperature curve to estimate the temperature at the surface? What is this temperature?

The base of the clouds is at an altitude of 50 kilometers. Do you see anything unusual about your curves at that altitude? Explain what may be happening in the Venus atmosphere to the bottom edge of the clouds.

3. Observation

When the two Pioneer-Venus spacecraft are launched to Venus, the planet can be seen in the evening sky. Once each week observe where Venus is, relative to the constellations, and make a continuing sketch of its movement relative to the stars during the voyage of the spacecraft to Venus. Watch for the time when Venus changes its eastward movement relative to the stars to a westward movement. Why does this happen? A sketch of the orbits as viewed from above with the positions of the planets every week will help you arrive at an explanation. You can derive the movement of the planets around their approximately circular orbits by using the information provided in Project 1. How much faster does Venus move along its orbit (in km/s) than the Earth? Why is this?

If you have access to a telescope (a 3-inch aperture telescope is suitable), also make sketches of the phase of Venus at each observation and prepare a series of drawings showing how the planet changes in apparent size as its phase changes. Why is this? Again use your orbital diagram of Earth and Venus seen from above the Sun. Approximately how far from Earth will Venus be when it passes between Earth and Sun at inferior conjunction?

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