Chapter 9 Venus: Earth's Sister Planet

Orbital Properties

Venus is the second planet from the Sun and as such it is inside of the Earth's orbit. That means that Venus only gets about 47° from the Sun in our sky. This means when Venus is at its maximum distance from the Sun we can see it for about 3 hours after sunset of sunrise. It is the third brightest object in the sky behind the Sun and the Moon. The reason it is so bright is that it reflects nearly 70% of the light that strikes it compared to the Moon's 10% reflectivity. This is due to the fact that Venus is covered in clouds. We would expect Venus to be the brightest when it is full. But when it is full it is on the far side of the Sun, 1.7 AU from the Earth. Venus is actually the brightest 36 days before or after the closest approach to the Earth when it is in a fat crescent phase.

Physical Properties

Radius, Mass, Density

The radius as calculated by spacecraft is 6052 km or .95 Earth radii. Like Mercury, Venus has no moon. This makes determining the mass more difficult. We used the small gravitational effects on the Earth to determine the mass, but since we have sent spacecraft to Venus, we now know the mass to be 4.9×10^{24} kg. This is 82% the Earth's mass. From the mass and radius we can calculate the density to be 5200 kg/m^3.

Rotation Rate

Determining the rotation rate for Venus is made very difficult by the same clouds that reflect the light. It wasn't until the 1960's with the advances in radar imaging that we could measure the rotation rate. Some astronomers thought the rate was 25 days and others thought it was 24 hours like the Earth. The fight went on until it was shown that the rate is actually 243 days. Not only that but it was found that it was in a retrograde motion, clockwise instead of counterclockwise like the rest of the solar system. Why does it rotate backwards? Most astronomers think that like the Earth, Venus was struck by a large object that slowed it down and made it go backwards. This causes problems for Earth bound observers. It makes about 5 rotations between each close approach. This means that the same side is always facing the Earth on its closest approach.

This nearly perfect 5:1 resonance is similar to the Moon's synchronous orbit with the Earth and Mercury's 3:2 spin-orbit resonance. But there is no known interaction between the Earth and Venus to cause this resonance. The key word here is nearly perfect resonance. Scientists don't like coincidences, but they can't explain why it is like that.

Long Distance Observations of Venus

Because of a number of similarities, Venus and the Earth are called sisters. Unlike the Earth, Venus has a very thick atmosphere which bocks out any views with optical instruments. We had more luck with atmospheric patterns when we viewed them in UV. As you can see from the overhead the UV brings out the features in the clouds. This was taken by the Pioneer Venus spacecraft. These are very similar to the high altitude jet streams on Earth. These upper clouds move at about 400 km/hr. Early spectroscopic studies of reflected light from Venus shows large amounts of CO_2, but showed little else.

In the early 1930's it was thought that Venus had temperatures very similar to the Earth's temperatures. Due to the proximity to the Sun, it was thought that the temperature would be 10 – 20 degrees warmer than Earth. Boy, were they wrong. In 1956 radio observations of the thermal emission from Venus were done and it was found that the blackbody spectrum showed a temperature of 730 K or 457° C. Today most of the studies done on Venus come from the Arecibo Observatory in Puerto Rico.

The Surface of Venus

We have obtained detailed radar images of Venus from the Venera, Pioneer Venus and Magellan spacecraft. This yields a radar map of the planets surface. The best images have come from the Magellan spacecraft that we sent to Venus. It radar mapped most of Venus.

Large Scale Topography

The overhead shows the Pioneer Venus data. It maps out the elevation of Venus, where white is the highest and blue the lowest areas. Venus appears relatively smooth with modest highlands and lowlands. There are 2 continent sized features called Ishtar Terra and Aphrodite Terra. These continents only occupy about 8% of the surface. The Earth's continents occupy 25% of the surface. Ishtar Terra is about the size of Australia. The highest point on Venus is the Maxwell Montes which rises 14 km above the deepest depression on Venus. On the Earth the highest point is Mt. Everest above the bottom of the Marianas Trench, some 20 km. The Venera photo shows wrinkles on Venus, which turn out to be chains of mountains. On the western side of the Maxwells lies a crater named Cleopatra, which is 100 km across. It is not volcanic, but rather meteoric in nature. There is some lava in Cleopatra due to the meteor breaching the surface of Venus and lava coming through. Before Magellan got to Venus, it was thought that Aphrodite Terra was a site something like the seafloor spreading just like on the Earth. The Magellan data tossed that out pretty quickly. The crust appears cracked and buckled. There also appears to have been repeated periods of extensive lava flows. There are a number of cracks on the surface which have been caused by lava. It is thought that lava welled up from below. As the lava withdrew, the weight of the new crust caused it to collapse and form the cracks that we now see. There is no evidence for any kind of plate tectonics.

Volcanism and Cratering

The planet Venus has extensive volcanic features. There are many *lava domes* on Venus. These are areas where the lava welled up from below and never pushed through the surface so you have these raised areas. Most of the volcanoes on Venus are *shield volcanoes*. They are similar to the Hawaiian Islands. They form at hot spots in the crust and are built up over a series of eruptions. At the top of the shield volcanoes you will find a *caldera*. This is where the lava withdrew from the opening and left this area where the lava collapsed. The volcanoes seem to be randomly distributed across Venus, unlike the Earth. This supports the idea that there is no plate tectonics.

The largest volcanic structures are called *coronae*. (singular is corona) These are areas that have been uplifted by lava underground. There are usually volcanoes on and around the corona.

Is there still volcanic activity or has it stopped? Well, some evidence says that there are still active volcanoes on Venus. The SO_2 in the upper atmosphere shows large and frequent variations. It is very possible that these variations are due to a volcanic eruption throwing out more SO_2. Also, Venera and Pioneer both observed bursts of radio energy similar to those produced on Earth when you have lightning discharges in the plumes of erupting volcanoes.
Not all of the craters on Venus are volcanic in nature. Some were formed by impacts. Due to the thick atmosphere, only the larger bodies make it through the atmosphere. The largest crater on Venus is 280 km across and is called Mead. It shows a double ring crater similar to some on the Moon. There are no craters less than about 3 km in diameter. By doing crater counts, some astronomers have calculated that the surface of Venus is only about 1 billion years old.

Data from the Soviet Landers
The Venera landers were the first spacecraft to send us pictures of the surface. Each lasted about an hour. The rocks in the pictures showed little signs of erosion. Later landers did a chemical analysis of the rocks and found that they were basaltic in nature. Later some material was found to resemble granite.

The Atmosphere of Venus
Atmospheric Structure
From our satellites we have a fairly detailed picture of the atmosphere of Venus. It is about 90x thicker than our own atmosphere. On the Earth the 90% level is found at 10 km altitude while on Venus the 90% level is found at 50 km. The atmosphere is much hotter and has a greater pressure than our own. However, the temperature drops off more quickly than our atmosphere and it is actually colder at the high altitudes than on Earth. The troposphere extends up to about 100 km. The clouds are at between 50 and 70 km. Down to about 30 km there is a haze and below that it is clear. Above the clouds you have a high speed jet stream that changes the upper clouds. Due to the thickness of the atmosphere, winds near the surface are only about 4 mph.

Atmospheric Composition
The atmosphere of Venus is made up primarily of CO_2, 96.5 % to be exact. The other 3.5 % is mainly nitrogen. There is trace amounts of other gases such as CO, SO_2, Ar, and water vapor. There is basically no oxygen here and the water vapor present is less than would be expected if there had been a large body of water. It has been determined that the upper clouds on Venus are actually made up of sulfuric acid droplets.

The Greenhouse Effect on Venus
Venus wasn't thought to be as hot as it is. Why is it so hot? And if we believe that it started off like us, what has happened? The answer to the first question is easy. Due to composition of the atmosphere it suffers from the *greenhouse effect*. Water vapor and CO_2 trap the heat from the Sun. Since the heat couldn't escape, the planet heated up. The more greenhouse gases there are, the more heat you trap. The circulation of the atmosphere causes the dark side to be about as hot as the day side.

The Runaway Greenhouse Effect

Why is the atmosphere so different from ours? Why is there is so much CO_2 in the atmosphere? On the Earth, much of the CO_2 and SO_2 was absorbed by the oceans. Much of what was left was absorbed by the rocks. If the Earth could release all of the CO2 that is trapped in the rocks or dissolved in water, our atmosphere would be 98% CO_2 and would be about 70x thicker.

On Venus we had what is known as the *runaway greenhouse effect*. If we could move the Earth to where Venus is this is what would happen: there would be more sunlight so we would warm up. More water would evaporate so the atmosphere would hold more heat. As it got hotter, the CO_2 would be baked out of the oceans and the rocks. This would mean the rise in CO_2 and hotter temperatures. As it got hotter, more water would evaporate and more CO2 would be baked out, which in turn would hold more heat making it hotter. It is a cycle known as the *runaway greenhouse effect*. This caused the water vapor to rise high into the atmosphere where it made sulfuric acid drops. Also high in the atmosphere the UV broke apart some of the water and the H escaped and left the oxygen on Venus.