Chapter 9: Venus
Earth's Sister Planet

Outline

9.1 Orbital Properties
9.2 Physical Properties
9.3 Long-Distance Observations of Venus
9.4 The Surface of Venus
9.5 The Atmosphere of Venus
9.6 Venus's Magnetic Field and Internal Structure

Summary

As you discuss each planet in this and subsequent chapters, it would be helpful to the students if you show Figures 6.5 and 6.7 prior to delving into the details of the particular planet under discussion. This keeps things in perspective with regard to each planet's relative size and orbital position in the solar system.

This chapter not only describes the planet Venus, but offers insight into how it evolved to a vastly different state than did the Earth. This suggests two very important issues that should be remembered. Two planets can start out almost the same and yet follow paths of change that lead to very different ends. The second issue is that planets can evolve. They change over time and that is not what was seen with Mercury and the Moon.

In studying Venus it is tempting to think in terms of "what went wrong" with Venus. But this is to assume that Earth developed "correctly." Neither concept is correct. They both evolved as they had to given their individual circumstances. Apparently even small differences in the beginning make for large differences in the resulting planet. As will be seen later in the text, this is not necessarily true for stars. It some ways it could be concluded that the evolution of planets is much more complex than for stars.

Major Concepts

- Orbital Properties
  - Proximity to the Sun as seen from Earth
- Physical Properties
  - Density
  - Mass
  - No Natural Satellites
  - Rotation
    - Very slow
    - Retrograde
- Observation of Venus
  - Imaging Probes
    - Venera
    - Pioneer
    - Magellan and Radar
- Surface
  - Volcanism / Lava Domes

    - Craters
    - Surface replacement every few hundred million years
- Atmosphere
    - Pressure
    - Carbon Dioxide and the Greenhouse Effect
    - Sulfuric Acid Clouds
- Lack of Magnetosphere

Teaching Suggestions and Demonstrations

Section 9.1

Venus is often termed the "Morning Star" and the "Evening Star." After introducing the fact that Venus is the second closest planet to the Sun, ask the students if they would ever expect to see Venus at midnight. Venus never ventures far from the Sun from our vantage point. Why? During most semesters, there will be at least a brief period of time in which to view Venus either in the morning before sunrise or in the evening after sunset. Because of its high albedo (0.67), Venus is usually a strikingly beautiful object to view, even with the unaided eye. An enjoyable and educational exercise is to bring in a current orbital position chart from one of the popular astronomy magazines. This is usually included as a fold-out section in each monthly issue. Have the students determine whether Venus is currently the "Evening Star" or "Morning Star" if visible at all. After having made that determination, have them locate it in the sky at the next available opportunity.

Section 9.2

Venus is very Earth-like in many respects, earning it the nickname of our "Sister Planet." Fortunately for us (and unfortunately for Venus), it is more like a distant cousin racked by illness. The density, mass, and size compare favorably to that of Earth. But, the atmosphere and surface features differ markedly.

One day on Venus would be equivalent to more than 240 earth days and the Sun would appear to rise in the West and set in the East. No moon would be visible ever, not because of the constant cloud cover, but because Venus has no companion. After describing Venus to my students, they usually say that it truly sounds like "hell."

Section 9.3

Both Venus and Mercury are observed to go through phases just like the Moon. For historical reasons the phases of Venus are the most important. Galileo first noted the changes of phase with his telescope. But the real importance of this was the phases were correlated with the brightness changes in Venus and the apparent size of Venus. At inferior conjunction Venus is both bright and large (as noted in the text, Venus is brightest just before and after inferior conjunction) and is seen as a thin crescent. At superior conjunction Venus appears faint and small and is in the full phase. Galileo became convinced that the correlation of phase with brightness and size was due to Venus orbiting the Sun, thus supporting the Copernican Theory. ➲ **DEMO** Demonstrate the changing phases of Venus (or Mercury) as seen from Earth using a light bulb for the Sun and a plain sphere for Venus. Photographs taken of Venus at various phases are an excellent way of showing what is actually seen and that it is not a subtle effect.

Chapter 5 provided background for understanding the advantages of astronomies at the various wavelengths. Optical telescopes and probes with visible wavelength sensors provided little information about the surface of Venus. Show Figure 9.6 again. This figure was provided courtesy of the *Pioneer* spacecraft, which had imaging sensors capable of viewing Venus in the UV and visible bands. Note the complete absence of surface information. In order to gain knowledge of the surface of Venus, we had to use wavelengths capable of reaching the surface itself. Provide a brief introduction to radar at this point. You really do not need to go into much more detail than to say that radar works by transmitting pulses of electromagnetic radiation capable of penetrating clouds. Each pulse is sent to and reflected from a known position on the planet's surface. The round-trip time is determined, which provides a range to each aim point. By maintaining a database of the aim points and ranges for each, the radar processing system can deduce the topographic profile for the imaged surface. Figures 9.7 and 9.8 resulted from this technique. Be sure to mention that these figures are shown in false color. Radar, in fact, does not "see" in color, only intensity and range. In addition to these figures, you will want to have on hand at least one image of the *Magellan* spacecraft. These can be found easily on the internet at any one of the NASA related websites.

Section 9.4

As mentioned in the previous section, show as many images of Venus as you can and be sure to include images from the *Pioneer*, *Venera* and *Magellan* programs. *Venera* is particularly interesting to discuss because it provided close-up images for only a brief time due to the intense heat and pressure, not to mention the sulfuric acid bath on its decent to the surface.

Compare the surface of Venus to that of Earth and Mercury. Contrast the very old surface of Mercury with the relatively young surface of Venus. Although both planets are the same age, the activity beneath Venus's surface and within its atmosphere accounts for a kind of slow boiling tortured existence. Mercury is essentially a solid body whose surface features are determined by external factors, while Venus is churning away effectively replacing its surface every few hundred million years or so. Venus is "active."

Contrast Venus's surface with Earth as well. Earth is volcanically active, but the volcanoes exist predominantly at tectonic plate interfaces. Venus, on the other hand, has apparently random locations for its volcanoes indicating a lack of tectonic activity. These hotspot volcanoes can be compared and contrasted to Olympus Mons on Mars, which is another example of hotspot volcanism in the absence of tectonic motion. Discuss the Hawaiian islands on Earth to contrast evidence of hotspot volcanism on moving tectonic plates. Again, comparative planetology at work.

Section 9.5

Most people take the atmospheric pressure on Earth for granted and do not think about it except when it varies due to weather conditions. They do not realize that the atmosphere is pressing on them with a force of 14.5 pounds for each square inch. (Sometimes it seems appropriate to regress to English units in order to make a point. Avoid doing this too often.) Ask students why they are not particularly aware of atmospheric pressure, which adds up to quite a force over the area of our bodies (about 15 to 20 tons!). The answer: fluid pressure inside our bodies is pressing outward with an equal and opposite force. We are in equilibrium. On the surface of Venus the atmospheric pressure is 90 times that of the Earth's atmosphere. The pressure would be about 1,300 pounds per square inch, which is truly a crushing force. You would have to be 50 km high in the atmosphere of Venus before the pressure would appear like the Earth's.

➲ **DEMO** Model Venus's atmosphere in the same way that was done for the Earth's atmosphere (1 cm = 1 km). Display Figure 9.17 as you discuss the scale thicknesses of the layers. Contrast the differences between Earth and Venus.

1 - 30 cm	Atmosphere is clear
30 - 50 cm	Layer of haze
50 cm	90% of the atmosphere is below
50 - 70 cm	Cloud layers composed of sulfuric acid
70 cm	Jet stream clouds moving at 300 - similar 400 km/hr
100 cm	Top of troposphere
200 cm	Top of mesosphere

Perhaps the most intriguing feature of Venus is the runaway greenhouse effect, which should be discussed in some detail since the greenhouse effect concerns us earthlings as well. Emphasize the importance of water being liquid on Earth in controlling the greenhouse effect here. Carbon dioxide dissolves fairly easily in water. Chemical reactions and the presence of life in the water bound the carbon dioxide into rock formations. More carbon dioxide would then be removed from the atmosphere and dissolved in the water and so forth. On Venus, both water and carbon dioxide were in the atmosphere as gases. With an ever-increasing greenhouse effect, the temperature rose. Any water that may have been in the crustal rocks and carbon dioxide that was chemical bound in rock is "cooked" out of the surface rocks and into the atmosphere. The water is eventually destroyed and the carbon dioxide remains.

The high temperatures on Venus are due to the combination of its proximity to the Sun as well as the presence of the greenhouse effect. Referring to the thermometer you may have assembled in the suggestions from Chapter 8, set both the high and low temperatures to 730 K. Venus has much more atmosphere than Earth, which insulates the surface and prevents large temperature variations from day to night and from polar to equatorial regions. Venus has the highest *average* surface temperature of any planet. Why? Mercury may have a higher surface temperature on the day side of the planet at any given time, but its lack of an atmosphere, or blanket, allows for the re-radiation of that heat at night. So, Mercury's atmosphere is too thin, Venus's atmosphere is too thick and Earth's is….just right! (for now).

The atmosphere of Venus is not only responsible for its high temperature but also for a very high **pressure**. Atmospheric pressure is due to the weight of all the air pushing down on the surface of Earth. We hardly notice, because we live with atmospheric pressure all the time. Bring a barometer to class and explain how it works. The pressure on the surface of Venus is about 90 atm, about equivalent to the pressure you would feel if you were 1000 meters under the surface of the ocean!

Asking the Right Question: The abundance of carbon dioxide and absence of water in the Venusian atmosphere, and the reasons for this, are excellent examples of why scientists have to make sure they are asking the right question. One cannot really answer the question "Why does Venus have so much carbon dioxide in its atmosphere?" The correct question is "Where is all the carbon dioxide that should be in the Earth's atmosphere?" Similarly one should not ask "Why does Earth have so much water?" but "What happened to the water on Venus?" Science cannot find the right answers if the original question is wrong! Progress is often made when a scientist gains new insight to a problem and finds a new way of stating a question that can then be answered.

Section 9.6

As if things weren't already bad enough, Venus is at the mercy of the high energy particles streaming from the Sun due to the fact that there is no appreciable magnetosphere to provide protection. Although no seismic experiments have been performed on Venus, it is likely that there is a molten iron core similar to that of Earth, but the extremely slow rotation rate of Venus, once in 243 Earth days, results in a lack of dynamo effect necessary to produce a magnetic field. Keeping in the spirit of comparative planetology, remind the students that Mercury has a similar, but not identical reason for its lack of magnetic field. Recall, Mercury rotates more rapidly than Venus, but is believed to possess a solid core, which itself is not capable of producing a magnetic field. The dynamo effect requires rotation *and* a molten iron core. Again, Mercury has no molten core, Venus has no appreciable rotation rate, while Earth has both.

Student Writing Questions

1. Describe what a typical day on Venus would be like.

2. Imagine Venus, when it was very young, as an Earth-like planet, with oceans and a small atmosphere. If life had developed, how might it have prevented Venus from getting so hot and forming such a large atmosphere?

3. If Venus started out with a normal rate of rotation, what are the various ways in which it might have been slowed to its current long period of rotation? Describe these processes in as much detail as possible.

4. Could Venus ever be changed back to a more habitable environment like Earth? What could be done? What difficulties stand in the way of accomplishing this change? How long might this change take if it is feasible?

5. The source of the clouds of Venus *may* be its volcanism. As the planet cools, ultimately this activity will cease. Assuming the clouds can eventually clear, what will Venus look like? Keeping in mind that the clouds reflect a large portion of the sunlight received by Venus, what changes in the Venusian environment might be anticipated?

Answers to End of Chapter Exercises

Review and Discussion

1. Venus is the third brightest object in the sky, after the Sun and Moon. It is completely covered by very reflective clouds so that much of the sunlight received by Venus is reflected back into space. Venus also is one of the closest planets to the Earth, depending on where it is in its orbit. This also helps make Venus appear bright. Its brightness depends on its phase and distance from the Earth.

2. Since Venus is an inner planet, it will never be found too far from the Sun. However, it is much easier to see than Mercury, having an orbit almost twice the size of Mercury's.

3. The "near-resonance" is not an exact one, as would be expected if it is real. The Earth does not exert a strong enough gravitational pull on Venus to be able to pull into this resonance.

4. The problem with the "near-resonance" is that the same side of Venus points towards Earth each time they are at closest approach. So one side gets mapped better than the other. Of

course the best mapping has been done in orbit around Venus, so this is no longer a significant problem.

5. It is possible that Venus was struck by a large object in just the right way to almost stop it from rotating.

6. Technically, you could not see Earth from the surface of Venus because of all the cloud cover of Venus. If you could see Earth, it would appear slightly larger than does Venus from Earth, a bit darker because of its lower albedo, and there would certainly be visible the blue, browns, and whites of the oceans, continents, and clouds and ice regions. Earth would not go through phases like Venus because it would be seen as an outer planet.

7. At one time, Venus was thought to have a warm, tropical environment. In the 1950s, radio observations of Venus measured its thermal emission. The radiation emitted by Venus has a Planck curve spectrum characteristic of a temperature near 600 K. It was hardly a tropical, habitable planet.

8. The ultraviolet images revealed fast-moving upper layers of clouds. These clouds had velocities of up to 400 km/hr.

9. The atmosphere of Venus has a total mass about 90 times greater than that of Earth and extends to a much greater altitude than that of Earth's atmosphere. 90 percent of the Earth's atmosphere lies within about 10 km of the surface, compared with 50 km on Venus. The surface temperature and pressure of Venus's atmosphere are much greater than Earth's.

10. The dominant component of the atmosphere of Venus is carbon dioxide. It accounts for 96.5 percent of the atmosphere by volume. Almost all of the remaining 3.5 percent is nitrogen. Trace amounts of other gases, such as water vapor, carbon monoxide, sulfur dioxide, and argon are also found. The clouds are made of sulfuric acid.

11. Venus has both a very thick atmosphere and one mostly composed of carbon dioxide. Carbon dioxide is a very effective greenhouse gas, trapping infrared light within the atmosphere and raising the temperature. This, in combination with the largeness of the atmosphere, has produced a very large greenhouse effect and a resulting high temperature.

    On Earth, almost all of the water vapor and carbon dioxide present in the planet's early atmosphere quickly became part of the surface of the planet, in the oceans or in the surface rocks. On Venus, the temperature may have been so high that no oceans condensed, in which case water vapor and carbon dioxide remained in the atmosphere. The carbon dioxide was never incorporated in the crust of Venus. The water was slowly broken down by solar ultraviolet light into hydrogen and oxygen. The hydrogen escaped into space and the oxygen formed oxides of sulfur and carbon.

12. When Venus was young, even with some liquid water, its higher temperature, due to its closeness to the Sun, increased atmospheric water and raised its temperature. This did not allow carbon dioxide to remain dissolved in the oceans, forcing it out into the atmosphere and further increasing the greenhouse effect and the temperature.

13. Its climate might be similar to Earth's. An important point to remember, however, is that Venus is a smaller planet with a lower surface gravity. It might not have been able to hold onto as much of an atmosphere as the Earth.

14. The continents of Venus make up only 8% of its surface, as compared to the 25% of the Earth's surface. They are not tectonically produced but do show extensive lava flows. The mountains are of similar height but are produced by upward convective flows and not the tectonic activity found on Earth.

15. There is a strong deficiency in small impact craters on Venus, due to its atmosphere destroying meteoroids smaller than about 1 km. The smaller impact craters show evidence of the meteoroid being shattered prior to impact. There is also a deficiency in larger craters, but this is likely due to the surface of Venus being resurfaced by volcanic activity.

16. Volcanic craters are very common on the surface of Venus. The largest features are the coronae, formed from upwelling mantle material. The deficiency in large impact craters suggests significant resurfacing by lava flows.

17. The level of sulfur dioxide above Venus's clouds show large and fairly frequent fluctuations which may be the result of volcanic eruptions. The *Pioneer* and the *Venera* orbiter observed bursts of radio energy from the Beta and Aphrodite regions, similar to those produced by lightning discharges that often occur in the plumes of erupting volcanoes on Earth.

18. The dynamo model for the production of planetary magnetic fields requires both an iron-rich core and a relatively rapid rate of rotation. Venus lacks the rapid rotation and therefore does not appear to produce a magnetic field. Actually, the fact that it does not have a magnetic field strongly suggests that the dynamo model is correct.

19. Life on Venus appears to be impossible due to its very high temperature. This temperature is sufficient to break down virtually any important molecules that would be necessary for life. In addition, the environment of sulfuric acid would be very destructive to these same molecules. The absence of water does not help either!

20. Earth's greater distance from the Sun and its large amount of liquid water on its surface are both factors that would help prevent a runaway greenhouse effect like that of Venus. Most of our carbon dioxide is locked away in the crustal rocks. It would all have to be released in order for Earth to become like Venus. This could only happen if Earth's temperature increases dramatically. But there are no mechanisms to heat the Earth to get this started. Venus started with higher temperatures because of its closeness to the Sun.

Conceptual Self-Test

1. F
2. F
3. F
4. F
5. T
6. F
7. T
8. T
9. F
10. T
11. A
12. C
13. C
14. B
15. B

16. C
17. B
18. C
19. A
20. A

Problems

1. Refer to *More Precisely 1-3*. Venus's true diameter is known to be 1.2x10^4 km. So, we get the angular diameter as follows:

   a) As given in the text, when Venus is brightest, its distance from Earth is 0.47 A.U. or 7.03x10^7 km. So,

   $$\frac{\text{True Dia.} \times 57.3^\circ}{\text{Distance}} = \frac{1.21 \times 10^4 \times 57.3^\circ}{7.03 \times 107} = \left(9.78 \times 10^{-3}\right)^\circ = 35.2''$$

   b) At greatest elongation, the distance between Earth and Venus is nearly 0.72 A.U., so

   $$\frac{\text{True Dia.} \times 57.3^\circ}{\text{Distance}} = \frac{1.21 \times 10^4 \times 57.3^\circ}{1.08 \times 10^8} = \left(6.42 \times 10^{-3}\right)^\circ = 23.1''$$

   c) At superior conjunction, the distance between Earth and Venus 1.7 AU, so

   $$\frac{\text{True Dia.} \times 57.3^\circ}{\text{Distance}} = \frac{1.21 \times 10^4 \times 57.3^\circ}{2.54 \times 10^8} = \left(2.73 \times 10^{-3}\right)^\circ = 9.8''$$

2. Venus's orbital speed is 35 km/s, 5 km/s faster than Earth. With 86,400 s in a day, Venus moves 432,000 km more than Earth. At a distance of closest approach, 42 million km, the angle will be 57.3° (0.432 / 42) = 0.59°. (Of course, this would not occur during the night but in full daylight.)

3. When Venus is brightest, it is 0.47 A.U. × 1.5×10^8 km/A.U. = 7.05×10^7 km distant. Dividing by the speed of light gives 235 s. Multiplying by 2 for a round trip gives 470 s or 7 minutes and 50 seconds.

   When Venus is closest, 0.28 A.U., this time will be reduced by the ratio of the distances; (0.28 / 0.43) × 430 = 280 s or 4 minutes and 40 seconds.

4. Using the information from *More Precisely 9–1*, for a prograde rotation, R = 243.0 and D = -2984 days.

5. Mercury, having a period of 88 days, revolves once (360º) in 88 days or 4.1º/day and Venus, having a period of 224.7 days, revolves once in 224.7 days or 1.6º/day. To determine the synodic period of Mercury as seen from Venus use; $1/S = (1/P_{mercury})-(1/P_{Venus})$ and solve for S. S = 145 (Earth) days.

6. The 73 day interval divides the orbit of Venus into 45° arcs and the orbit of the Earth into 72° arcs. Number the tic marks along each orbit

7. At closest approach, Earth is 0.28 A.U. or 4.2x10^7 km distant. The tidal gravitational acceleration, a_t, on Venus (between center and surface) due to Earth at closest approach is given by

$$a_t = \frac{GM_{Earth}R}{r^3} = \frac{6.673\times10^{-11}\times5.97\times10^{24}\times6.05\times10^{6}}{\left(4.2\times10^{10}\right)^3} = 3.25\times10^{-11}\ \text{m/s}^2,$$

where r is the distance between Venus and Earth and R is the radius of Venus, 6.05x10^6 m. The surface gravity on Venus is known to be 8.87 m/s^2. Therefore, the tidal gravitational acceleration due to Earth is about a factor of **3.7x10^{-12}** that of Venus's surface gravity.

For the Sun's tidal effect on Venus:

$$a_t = \frac{GM_{Sun}R}{r^3} = \frac{6.673\times10^{-11}\times1.99\times10^{30}\times6.05\times10^{6}}{\left(1.08\times10^{11}\right)^3} = 6.38\times10^{-7}\ \text{m/s}^2,$$

where r is the distance between Venus and the Sun. This is **7.2x10^{-8}** times Venus's surface gravity.

8. Rather than setting up the usual ratio, use the formula $s = r\theta$, where s is the size of an object at distance r and angular size θ. The angular size must be given in radians, a unitless form for angles. One radian = 57.29577951° ≈ 57.3° = 3438' = 206,265". Thus, one arc minute = 0.00029 rad. Since r = 0.28 A.U. = 42,000,000 km, s = 12,200 km.

9. 0.1" = 206,000" (D / 42,000,000 km). D = 20 km. Most of the craters on Venus are larger than this limit and would therefore be detectable.

10. At 300,000 km/s, a radar wave will travel 3 km in 10^{-5} s.

11. The circumference of Venus is 2 π 6,051 km = 38,020 km. The distance covered in 4 days or 96 hours gives 400 km/hr. A kilometer is about 5/8 of a mile, so this is about 250 miles per hour.

12. The volume of the atmosphere is the surface area of Venus times the thickness of the atmosphere. This volume times the density will equal the mass. $4\pi(6.051\times10^6\ \text{m})^2 \times 50000\ \text{m} \times 21\ \text{kg/m}^3 = 4.8\times10^{20}$ kg. From Chapter 7, problem 3, the mass of Earth's atmosphere is 5.0×10^{18} kg. The mass of Venus's atmosphere is 97 times this.

13. The amount of radiation emitted per square meter is proportional to the fourth power of the temperature. $(730/300)^4 = 35$, so Venus radiates 35 times more than the Earth.

14. Since the luminosity in Stefan's law is proportional to T^4, compare Venus at 250 K to Venus at 730 K. $(250 / 730)^4 = 0.014$. Subtracting this from 1 gives 0.986 or 98.6%.

15. Use Kepler's third law in the form given in *More Precisely 2–3*. The major axis will be the total of 6051 + 294 = 6345 km and 6051 + 8543 = 14594 km. The semi-major axis is 10,470 km or 1.05×10^7 m.

$$P = 2\pi\sqrt{\frac{\left(1.05\times10^{7}\right)^{3}}{6.7\times10^{-11}\times4.87\times10^{24}}}$$

P = 11,800 s or 200 minutes

The new semi-major axis is 6411 km. The new period is 94 minutes.

Resource Information

Student CD Media

Movies/Animations
The Phases of Venus
The Rotation of Venus

Interactive Student Tutorials
Greenhouse Effect
Super Spaceship – Voyage to Venus

Physlet Illustrations
None

Transparencies

T-77	Figure 9.3	Terrestrial Planets	p. 232
T-78	Figure 9.6	Venus, Up Close	p. 233
T-79	Figure 9.7	Venus Mosaics	p. 236
T-80	Figure 9.8	Venus Maps	p. 237
T-81	Figure 9.9/10	Ishtar Terra and Aphrodite Terra	p. 238
T-82	Figure 9.11/12	Lava Flows and Lava Domes	p. 239
T-83	Figure 9.17	Venus's Atmosphere	p. 243
T-84	Figure 9.19	Greenhouse Effect on Earth and Venus	p. 245

Materials

1-World Globes (www.1worldglobes.com) sells a very nice globe of Venus. Fun to pass around the class while showing slides of *Magellan* images.

Suggested Readings

Bullock, Mark A.; Grinspoon, David H. "Global climate change on Venus." *Scientific American* (Mar 1999). p.50. Discusses the hypothesis that volcanism and climate change on Venus are linked.

Grinspoon, David H. "Venus unveiled." *Astronomy* (May 1997). p.44. Describes the observations of impact craters on Venus and discusses the implications about the history of the surface.

Kargel, Jeffrey S. "The Rivers of Venus." *Sky & Telescope* (Aug 1997). p. 32. Discusses lava flows on Venus.

Krupp, E. C. "Falling for the evening star." *Sky & Telescope* (May 1996). p. 60. Discusses the mythology associated with Venus.

Krupp, E. C. "The camera-shy planet: Venus." *Sky & Telescope* (Oct 1999). p. 93. Discusses the history of observing cloud-covered Venus.

Lubick, N. "Goldilocks and the Three Planets." *Astronomy* (July 2003). p. 36. Outstanding and very useful (in the classroom) article comparing Venus, Earth and Mars. Excellent comparative planetology.

Panek, Richard. "Venusian testimony." *Natural History* (June 1999). p. 68. Discusses Galileo's observations of the phases of Venus, and how this observation contributed to the heliocentric model of the solar system.

Sheehan, William; Dobbins, Thomas. "Charles Boyer and the clouds of Venus." *Sky & Telescope* (June 1999). p. 56. Discusses the pre-Mariner discovery of the rotation period of cloud tops on Venus.

Slater, T. "Inner Solar System Concepts." *The Physics Teacher* (May 2000). p. 264. Discusses teaching comparative planetology on a conceptual level.

Solomon, Sean C.; Bullock, Mark A.; Grinspoon, David H. "Climate change as a regulator of tectonics on Venus." *Science* (Oct 1, 1999). p. 87. Discusses the relation between tectonics, volcanism, and climate change on Venus.

Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: