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?

Chapter Review Answers

REVIEW AND DISCUSSION

1. Venus is the third brightest object in the sky, after the Sun and Moon. It is completely covered by clouds that reflect much of the sunlight received by Venus back into space. It receives a great deal of sunlight to reflect because it is so close to the Sun. Venus also is one of the closest planets to the Earth, depending on where it is in its orbit. This also helps Venus appear very 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. It is impossible for Earth to get between Venus and the Sun, and so Venus gets 47 degrees away from the Sun in the sky at maximum. However, its orbit is almost twice the size of Mercury's, so at least Venus can be much easier to see than Mercury.

3. Our best explanation is that Venus was struck by a large object at just the right angle and speed to slow and even reverse its spin.

4. 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 730 K – hardly tropical!

5. The ultraviolet images revealed fast-moving upper layers of clouds. This includes a "jet stream," where clouds have velocities of up to 400 km/hr.

6. The atmosphere of Venus is composed primarily of carbon dioxide, which is a minor constituent of the Earth's atmosphere. 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. The lower atmosphere of Venus is much less active than Earth's troposphere.

7. The dominant component of the atmosphere of Venus is carbon dioxide, accounting 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 in the upper atmosphere are made crystals of sulfuric acid.

8. Venus has a very thick atmosphere mostly composed of carbon dioxide. Carbon dioxide is a very effective greenhouse gas, as carbon dioxide is transparent to the visible light of the Sun, but absorbs infrared radiation emitted from the planet's surface. Although the carbon dioxide molecules must immediately release the infrared photons in a random direction, there are so many molecules that the photons "bounce"

from molecule to molecule million of times. This prevents infrared light from immediately escaping into space and raises the temperature to incredible levels all over the planet. Earth has a small amount of carbon dioxide, which helps keep the planet's average temperature well above the freezing point of water and makes life possible. This is because on Earth, almost all of the carbon dioxide present in the planet's early atmosphere dissolved in the oceans or became incorporated into carbonate surface rocks. Venus is so close to the Sun that it was likely too hot for large oceans to condense from water vapor, so that carbon dioxide remained in the atmosphere. The water vapor was slowly broken down by solar ultraviolet light into hydrogen and oxygen. The hydrogen escaped into space and the oxygen formed compounds with sulfur and carbon. The carbon dioxide was never incorporated into the crust of Venus, and the atmosphere remained thick and stifling.

9. If Venus were at Earth's distance from the Sun, it would likely be cool enough to have extensive oceans of liquid water. Therefore, it is likely that it would have followed a similar path of climate development as the Earth. Venus is smaller than the Earth, however, with a lower surface gravity. It might not have been able to hold onto as much of an atmosphere as the Earth.

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

11. There are very few small impact craters on Venus, because meteoroids smaller than about 1 km are destroyed as they travel through the thick atmosphere. The smaller impact craters that do exist appear to have been created by larger bodies that shattered prior to impact. There are also few very large craters, but such large meteoroids were more common in the very early days of the solar system, and ancient large craters may have been filled in by fairly recent lava flows on the surface.

12. Volcanic features are very common on the surface of Venus. The mountains of Venus are primarily volcanic in origin, and there are long, sinuous channels cut by past flowing lava. Lava domes of a variety of sizes are found on the surface, the largest of which are the coronae, formed from upwelling mantle material. The small number of large impact craters suggests significant resurfacing by lava flows throughout Venus' history.

13. The levels of sulfur dioxide above Venus' 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. The *Venus Express* has also detected unusually hot places on the surface of Venus that may indicate ongoing volcanic activity.

14. In order for a planet to be actively generating a magnetic field, it must have a core made of an electrically-conducting material such as iron, and it must be spinning relatively rapidly. 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.

15. 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 carbonate rocks in the crust, or dissolved into the oceans. Most or all of that would have to be released in order for Earth to become like Venus, and this could only happen if Earth's temperature were to increase dramatically. There appear to be no mechanisms to heat the Earth sufficiently to "jump-start" this process, although the possibility of warming caused by the release of carbon dioxide by human

activities is a potential source of concern. Venus started with higher temperatures because of its closeness to the Sun.

CONCEPTUAL SELF-TEST

1. A
2. C
3. C
4. B
5. B
6. C
7. B
8. C
9. A
10. A

PROBLEMS

1. The formula for angular diameter in seconds of arc is

angular diameter = 206,000 (actual diameter / distance)

The true diameter of Venus is 12×10^4 km, and the various distances are given in the first two sections of the chapter.

a. When Venus is brightest, Distance = 0.47 AU = 7.05×10^7 km;

$$\text{angular diameter} = 206265\left(\frac{12\times10^4\,km}{7.05\times10^7\,km}\right) = 35.1 \text{ arc seconds}$$

b. At greatest elongation, Distance = 0.72 AU = 1.08×10^8 km;

$$\text{angular diameter} = 206265\left(\frac{12\times10^4\,km}{1.08\times10^8\,km}\right) = 22.9 \text{ arc seconds}$$

c. At superior conjunction, Distance = 1.7 AU = 2.55×10^8 km;

$$\text{angular diameter} = 206265\left(\frac{12\times10^4\,km}{2.55\times10^8\,km}\right) = 9.7 \text{ arc seconds}$$

2. The orbital speed of Venus is 35 km/s, and since its orbit is very close to a perfect circle, we can assume that the speed will remain reasonably constant over the orbit. During one day (86,400 s), Venus will therefore travel 3,024,000 km. However, the Earth is also moving, at an average speed of 29.79 km/s, and in that same time span the Earth travels 2,574,000 km. Since they are both traveling in the same direction, we subtract those two numbers to find the motion of Venus with respect to Earth, 450,000 km. Venus is 0.28 AU (= 42,000,000 km) from Earth at closest approach, and so we can find the angular distance:

$$\text{angular distance} = 57.3\left(\frac{450,000}{42,000,000}\right) = 0.61^\circ \text{ per day}$$