Solutions

1. What are the main challenges involved in sending probes to the giant planets?

   There are many challenges, mainly the huge distances that require many years of flight time. The spacecraft must be reliable and robust to survive the journey. The low temperatures of space require onboard heating so the components don't freeze. The light levels are too low for solar panels to provide enough energy, requiring onboard power systems. Transmitters must be powerful enough to communicate with Earth over the vast distances of space. A somewhat more advanced answer might also include: at low light levels, photographs require longer exposures; however, fast-moving spacecraft will change position during these times and smear the image unless the arm with the camera moves backward at the same rate that the spacecraft moves forward.

2. Explain why visual observation of the gas giants is not sufficient to determine their rotation periods, and what evidence was used to deduce the correct periods.

   What is seen visually on each of these worlds is the upper atmosphere, with winds and storms that do not necessarily move at the same rate as the planet as a whole. Radio observations revealed the existence of magnetic fields originating in the cores of these planets. The rotation periods are determined from the fact that the magnetic fields rotate at the same velocity as the interiors.

3. What is the consequence of Uranus' spin axis being 98° away from perpendicular to its orbital plane?

   This essentially means that Uranus is on its side, with the poles alternately facing toward and away from the Sun. Each pole experiences long periods of light and darkness. The seasons alternate between half the planet being in the light and half in darkness for one season, to the planet's axis being sideways to the Sun and its rotation causing regular alternation of light and dark for the next season.

4. At the pressures in Jupiter's interior, describe the physical state of the hydrogen found there.

   The pressure is so high that the hydrogen, normally a gas, has been compressed into a liquid-metallic form not seen on Earth.

5. Which of the gas giants has the largest icy/rocky core compared to its overall size?

   From Table 11.3 Basic Properties of the Jovian Planets, we see that Neptune has the largest core, extending out to about 20,000 km from the center of the planet.

6. In the context of the giant planets and the conditions in their interiors, what is meant by "rock" and "ice"?

   Scientists describe materials in these environments that are composed primarily of iron, silicon, and oxygen as "rock." Similarly, those composed of carbon, nitrogen, and oxygen in combination with hydrogen are described as "ice." The layers described in this way don't necessarily resemble rocks and ice sheets on Earth.

7. What is the primary source of Jupiter's internal heat?

   Most of the internal energy of Jupiter is primordial heat, left over from the formation of the planet 4.5 billon years ago, when it gathered together from smaller "planetesimals" and accreted gas; the gravitational energy lost as these "building blocks" fell together turned into heat.

8. Describe the interior heat source of Saturn.

   The mantle of Saturn is still differentiating: The heavier helium is sinking, displacing the lighter hydrogen, which then rises. The "falling" of the helium releases gravitational energy, which heats the interior.

9. Which planet has the strongest magnetic field, and hence the largest magnetosphere? What is its source?

Jupiter has the largest magnetosphere. The large, rapidly spinning, liquid-metallic hydrogen above the core is the source of its magnetic field.

10. What are the visible clouds on the four giant planets composed of, and why are they different from each other?

The clouds of Jupiter and Saturn are primarily crystals of frozen ammonia. On Uranus and Neptune, the clouds are composed of methane. The temperatures of these worlds dictate the cloud composition. For Jupiter and Saturn, the temperatures keep methane in a gaseous state, while on Uranus and Neptune, the colder temperatures allow the methane to freeze and condense into clouds.

11. Why do the upper levels of Neptune's atmosphere appear blue?

The gaseous molecules in Neptune's atmosphere scatter blue light, giving Neptune its color. The same process makes Earth's sky appear blue.

12. How do storms on Jupiter differ from storm systems on Earth?

The cyclonic storm features on Jupiter are regions of high pressure, whereas storms on Earth, such as hurricanes, are low-pressure areas.

13. Describe the differences in the chemical makeup of the inner and outer parts of the solar system. What is the relationship between what the planets are made of and the temperature where they formed?

The inner solar system is much more abundant in "metals," the term astronomers use for the elements heavier than oxygen. The crust of Earth, for example, contains heavy elements all the way up to uranium. The outer solar system beyond the asteroid belt is much more abundant in the light elements. As we know from this chapter, Jupiter and Saturn are composed chiefly of hydrogen and helium. Uranus and Neptune also contain hydrogen, but contain more "ices" of carbon, oxygen, and nitrogen. The temperatures in the solar nebula from which the planets and Sun formed were much hotter closer to the Sun. As the heavier elements migrated toward the inner solar system due to gravity, they became locked up in the rocky planets like Earth. But due to their small size (and thus weaker gravity), plus the high temperatures of the inner solar system, these planets were unable to accumulate and hold on to the lighter elements, especially hydrogen and helium. Jupiter and Saturn, being farther away from the Sun and its heat, were able to keep growing and amass huge quantities of hydrogen and helium. (If the progenitor bodies that became Jupiter and Saturn had been closer to the Sun, they likely would be "just" rocky planets today.) In short, high temperatures means less hydrogen and helium, and vice versa.

14. How did the giant planets grow to be so large?

In the absence of the substantial heat planets experience near the Sun in the inner solar system, the rocky and icy bodies that would become the cores of the jovian worlds were able to continue to grow. Far from the Sun, the hydrogen and helium did not get enough energy from the Sun's heating to escape the growing gravitational fields of the cores, and the planets kept accumulating material. By the time the heat from the gravitational collapse of these bodies became large enough to provide internal heating, they were already too massive to permit hydrogen and helium to use this energy and escape into space. Thus, the outer planets grew until local conditions changed and no material was left for further growth.