Solutions

1. In what ways are meteorites different from meteors? What is the probable origin of each?

Meteorites are large enough to withstand the violent passage through Earth's atmosphere, whereas meteors burn up from the heat of friction. Meteors typically come from comets that have passed through the solar system; their solid material is freed when the ice is vaporized by the heat of the Sun. Most meteorites, on the other hand, are from asteroids or from debris kicked up on the Moon or Mars during an impact.

2. How are comets related to meteor showers?

Most meteor showers originate with particular comets that pass through the inner solar system and lose some of their solid material, which then goes into orbit along the comet's path. Showers happen whenever Earth in its orbit passes through the path of the comet and its debris.

3. What do we mean by primitive material? How can we tell if a meteorite is primitive?

Primitive material was formed in the early stage of the solar system, before planets cooled off enough to differentiate elements of different density. It was not subject to great heat or pressure after it formed. We can identify primitive meteorites by their composition; primitive meteorites are usually undifferentiated stones, with some metallic grains mixed in. Some primitive meteorites are darker, carbonaceous stones.

4. Describe the solar nebula, and outline the sequence of events within the nebula that gave rise to the planetesimals.

The solar nebula was initially a cloud of dust and gas that began to rotate around its center due to conservation of angular momentum as it contracted by gravitational attraction. The central region of the nebula became a star, while the outer regions flattened and made a rotating disk. Things near the center remained hot, while farther out in the disk things cooled off. Grains or droplets of material condensed (heavier solid materials could survive the heat in the inner parts, but volatile materials (droplets or ices) could survive only farther out. Closer in, particles began to cool and form compounds, including rock and metal grains that grew larger by gravitational impacts and mergers. Farther out, the droplets and icy pieces were able to grow. Accretion of these larger pieces (rock or ice) formed planetesimals.

5. Why do the giant planets and their moons have compositions different from those of the terrestrial planets?

Planets formed initially through the accretion of solid materials in the solar nebula. Due to the temperature in the interior of the solar system, the only substances capable of condensing there were rocks and metals. Any volatile materials could not condense so close to the heat of the early Sun. In the outer solar system, rock, metal, and hydrogen compounds (ices) were all solids and, as a result, there was much more material to form planets. The protoplanets that formed were large enough to also capture H and He gas and grow much, much larger and become the giant planets.

6. How do the planets discovered so far around other stars differ from those in our own solar system? List at least two ways.

A much greater variety of planets has been found around other stars than exists in our solar system. Large Jupiter-sized planets ("hot Jupiters") have been found orbiting close to their stars, which challenges our simple view of planetary system formation. There are also super-Earths and mini-Neptunes, planets intermediate in size between the terrestrial and jovian planets in our solar system. And a number of exoplanets have eccentric orbits, unlike the planets of the solar system.

7. Why are some planets and moons more geologically active than others?

First of all, a world needs to be solid to have geological activity. Among the terrestrial planets, geological activity depends to a large degree on the size of the planet and resulting internal heat; larger planets are better able to retain their primordial heat or to keep the heat from the decay of radioactive materials inside them. The Moon and Mercury, being small, are now geologically dead. Mars, Earth, and Venus all exhibit volcanism, but less for Mars as it has cooled more due to its smaller size. Some of the moons of the outer planets are geologically active due to heat caused by structural flexing in the large gravitational fields of the giant planets. How this internal activity manifests on the surface also depends on the composition of the object.

8. Why do meteors in a meteor shower appear to come from just one point in the sky?

All the meteors in a meteor shower typically come from the same comet, which is in a periodic orbit around the Sun. The loosened dust from the comet follows the path of the parent body. As Earth intersects the debris along the comet's orbit, it plows into this material. Since the dust particles are all moving together in space before they encounter Earth, if you trace back the streak of each meteor, its path will appear to diverge from one place in the sky called the radiant.

9. Why do iron meteorites represent a much higher percentage of finds than of falls?

The iron meteorites are much less common than the stones, if we count all the material that falls on Earth. However, iron meteorites are much easier to recognize than the stones, which tend to resemble rocks from Earth and are easily overlooked. In fact, irons make up nearly half of all finds.

10. Why is it more useful to classify meteorites according to whether they are primitive or differentiated rather than whether they are stones, irons, or stony-irons?

The traditional classification of meteorites into irons, stones, and stony-irons is simple to use because by looking at a meteorite one can tell which category it falls into (but it may sometimes be difficult to tell the difference between a meteoritic and terrestrial stone). However, classifying meteorites as primitive or differentiated gives information about their parent bodies, which is crucial in determining the origins of the meteorites.

11. How do we know when the solar system formed? Usually we say that the solar system is 4.5 billion years old. To what does this age correspond?

The "age of the solar system" is defined to be the same as the age of its oldest members, which are the primitive meteorites. We use the radioactive materials in such meteorites to date them.

12. We have seen how Mars can support greater elevation differences than Earth or Venus. According to the same arguments, the Moon should have higher mountains than any of the other terrestrial planets, yet we know it does not. What is wrong with applying the same line of reasoning to the mountains on the Moon?

The maximum height of mountains on a planet is governed by the surface gravity of the planet $\left(g \mu \ M/R^2 \right).$ The bigger the planet, the smaller the mountains (because if a mountain were larger, it could not support itself at its base). Mars is smaller than Earth and Venus and, in fact, has larger mountains. It is true that, by this reasoning, the Moon could have higher mountains than any of the other terrestrial planets. But the Moon is a geologically dead world with no internal activity anymore. The mountains on the Moon were formed by impacts, and such impacts simply do not make huge mountains. The mountains of Mars are primarily volcanic, and these types of mountains can be quite large, as we see in Olympus Mons, for example.

13. Present theory suggests that giant planets cannot form without condensation of water ice, which becomes vapor at the high temperatures close to a star. So how can we explain the presence of jovian-sized exoplanets closer to their star than Mercury is to our Sun?

Astronomers now believe that large planets may form far from their star, where low temperatures allow for condensation of ice, and then migrate inward closer to the star. This idea would also explain the higher eccentricity of some exoplanet orbits, which could occur during migration of a planet through a planetary system.

14. Why are meteorites of primitive material considered more important than other meteorites? Why have most of them been found in Antarctica?

Meteorites of primitive material have not been changed by heat or pressure since they formed, and thus give us an idea of the composition of objects in the early history of the solar system. The fact that some of them contain organic compounds or have water bound in them gives us greater insight into how the early planets may have obtained these materials. These meteorites are often difficult to identify when near rocks from Earth, but those that land in Antarctica are easier to spot against the snow and ice. They are also preserved by the isolated conditions of the South Pole and over time are concentrated on the icy surface.