9.4 The Origin of the Moon

Learning Objectives

By the end of this section, you will be able to:

- Describe the top three early hypotheses of the formation of the Moon
- Summarize the current “giant impact” concept of how the Moon formed

Ideas for the Origin of the Moon

It is characteristic of modern science to ask how things originated. Understanding the origin of the Moon has proven to be challenging for planetary scientists, however. Part of the difficulty is simply that we know so much about the Moon (quite the opposite of our usual problem in astronomy). As we will see, one key problem is that the Moon is both tantalizingly similar to Earth and frustratingly different.

Most of the earlier hypotheses for the Moon’s origin followed one of three general ideas:

1. The fission theory—the Moon was once part of Earth, but somehow separated from it early in their history.
2. The sister theory—the Moon formed together with (but independent of) Earth, as we believe many moons of the outer planets formed.
3. The capture theory—the Moon formed elsewhere in the solar system and was captured by Earth.

Unfortunately, there seem to be fundamental problems with each of these ideas. Perhaps the easiest hypothesis to reject is the capture theory. Its primary drawback is that no one knows of any way that early Earth could have captured such a large moon from elsewhere. One body approaching another cannot go into orbit around it without a substantial loss of energy; this is the reason that spacecraft destined to orbit other planets are equipped with retro-rockets. Furthermore, if such a capture did take place, the captured object would go into a very eccentric orbit rather than the nearly circular orbit our Moon occupies today. Finally, there are too many compositional similarities between Earth and the Moon, particularly an identical fraction of the major isotopes[2] of oxygen, to justify seeking a completely independent origin.

The fission hypothesis, which states that the Moon separated from Earth, was suggested in the late nineteenth century. Modern calculations have shown that this sort of spontaneous fission or splitting is impossible. Furthermore, it is difficult to understand how a Moon made out of terrestrial material in this way could have developed the many distinctive chemical differences now known to characterize our neighbor.

Scientists were therefore left with the sister hypothesis—that the Moon formed alongside Earth—or with some modification of the fission hypothesis that can find a more acceptable way for the lunar material to have separated from Earth. But the more we learned about our Moon, the less these old ideas seem to fit the bill.

The Giant Impact Hypothesis

In an effort to resolve these apparent contradictions, scientists developed a fourth hypothesis for the origin of the Moon, one that involves a giant impact early in Earth’s history. There is increasing evidence that large chunks of material—objects of essentially planetary mass—were orbiting in the inner solar system at the time that the terrestrial planets formed. The giant impact hypothesis envisions Earth being struck obliquely by an object approximately one-tenth Earth’s mass—a “bullet” about the size of Mars. This is very nearly the largest impact Earth could experience without being shattered.

Such an impact would disrupt much of Earth and eject a vast amount of material into space, releasing almost enough energy to break the planet apart. Computer simulations indicate that material totaling several percent of Earth’s mass could be ejected in such an impact. Most of this material would be from the stony mantles of

2 Remember from the Radiation and Spectra chapter that the term isotope means a different “version” of an element. Specifically, different isotopes of the same element have equal numbers of protons but different numbers of neutrons (as in carbon-12 versus carbon-14.)

Earth and the impacting body, not from their metal cores. This ejected rock vapor then cooled and formed a ring of material orbiting Earth. It was this ring that ultimately condensed into the Moon.

While we do not have any current way of showing that the giant impact hypothesis is the correct model of the Moon’s origin, it does offer potential solutions to most of the major problems raised by the chemistry of the Moon. First, since the Moon’s raw material is derived from the mantles of Earth and the projectile, the absence of metals is easily understood. Second, most of the volatile elements would have been lost during the high-temperature phase following the impact, explaining the lack of these materials on the Moon. Yet, by making the Moon primarily of terrestrial mantle material, it is also possible to understand similarities such as identical abundances of various oxygen isotopes.

9.5 Mercury

Learning Objectives

By the end of this section, you will be able to:

- Characterize the orbit of Mercury around the Sun
- Describe Mercury’s structure and composition
- Explain the relationship between Mercury’s orbit and rotation
- Describe the topography and features of Mercury’s surface
- Summarize our ideas about the origin and evolution of Mercury

Mercury’s Orbit

The planet Mercury is similar to the Moon in many ways. Like the Moon, it has no atmosphere, and its surface is heavily cratered. As described later in this chapter, it also shares with the Moon the likelihood of a violent birth.

Mercury is the nearest planet to the Sun, and, in accordance with Kepler’s third law, it has the shortest period of revolution about the Sun (88 of our days) and the highest average orbital speed (48 kilometers per second). It is appropriately named for the fleet-footed messenger god of the Romans. Because Mercury remains close to the Sun, it can be difficult to pick out in the sky. As you might expect, it’s best seen when its eccentric orbit takes it as far from the Sun as possible.

The semimajor axis of Mercury’s orbit—that is, the planet’s average distance from the Sun—is 58 million kilometers, or 0.39 AU. However, because its orbit has the high eccentricity of 0.206, Mercury’s actual distance from the Sun varies from 46 million kilometers at perihelion to 70 million kilometers at aphelion (the ideas and terms that describe orbits were introduced in Orbits and Gravity).

Composition and Structure

Mercury’s mass is one-eighteenth that of Earth, making it the smallest terrestrial planet. Mercury is the smallest planet (except for the dwarf planets), having a diameter of 4878 kilometers, less than half that of Earth. Mercury’s density is 5.4 g/cm^3, much greater than the density of the Moon, indicating that the composition of those two objects differs substantially.

Mercury’s composition is one of the most interesting things about it and makes it unique among the planets. Mercury’s high density tells us that it must be composed largely of heavier materials such as metals. The most likely models for Mercury’s interior suggest a metallic iron-nickel core amounting to 60% of the total mass, with the rest of the planet made up primarily of silicates. The core has a diameter of 3500 kilometers and extends out to within 700 kilometers of the surface. We could think of Mercury as a metal ball the size of the Moon surrounded by a rocky crust 700 kilometers thick (Figure 9.20). Unlike the Moon, Mercury does have a weak magnetic field. The existence of this field is consistent with the presence of a large metal core, and it suggests that at least part of the core must be liquid in order to generate the observed magnetic field.[3]