

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 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

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.)

- › 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

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's Orbit

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]

3 Recall from the [Radiation and Spectra](#) chapter that magnetism is an effect of moving electric charges. In atoms of metals, the outer electrons are easier to dislodge and they can form a current when the metal is in liquid form and can flow.

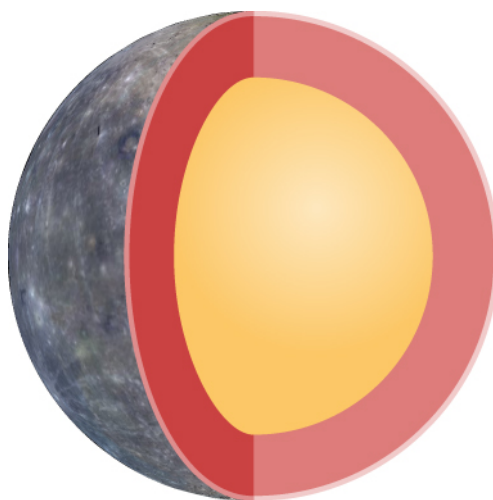


Figure 9.20 Mercury's Internal Structure. The interior of Mercury is dominated by a metallic core about the same size as our Moon.

EXAMPLE 9.1

Densities of Worlds

The average density of a body equals its mass divided by its volume. For a sphere, density is:

$$\text{density} = \frac{\text{mass}}{\frac{4}{3}\pi R^3}$$

Astronomers can measure both mass and radius accurately when a spacecraft flies by a body.

Using the information in this chapter, we can calculate the approximate average density of the Moon.

Solution

For a sphere,

$$\text{density} = \frac{\text{mass}}{\frac{4}{3}\pi R^3} = \frac{7.35 \times 10^{22} \text{ kg}}{4.2 \times 5.2 \times 10^{18} \text{ m}^3} = 3.4 \times 10^3 \text{ kg/m}^3$$

Table 9.1 gives a value of 3.3 g/cm^3 , which is $3.3 \times 10^3 \text{ kg/m}^3$.

Check Your Learning

Using the information in this chapter, calculate the average density of Mercury. Show your work. Does your calculation agree with the figure we give in this chapter?

Answer:

$$\text{density} = \frac{\text{mass}}{\frac{4}{3}\pi R^3} = \frac{3.3 \times 10^{23} \text{ kg}}{4.2 \times 1.45 \times 10^{19} \text{ m}^3} = 5.4 \times 10^3 \text{ kg/m}^3$$

That matches the value given in **Table 9.1** when g/cm^3 is converted into kg/m^3 .

Mercury's Strange Rotation

Visual studies of Mercury's indistinct surface markings were once thought to indicate that the planet kept one face to the Sun (as the Moon does to Earth). Thus, for many years, it was widely believed that Mercury's rotation period was equal to its revolution period of 88 days, making one side perpetually hot while the other was always cold.

Radar observations of Mercury in the mid-1960s, however, showed conclusively that Mercury does not keep one side fixed toward the Sun. If a planet is turning, one side seems to be approaching Earth while the other is moving away from it. The resulting Doppler shift spreads or broadens the precise transmitted radar-wave frequency into a range of frequencies in the reflected signal (Figure 9.21). The degree of broadening provides an exact measurement of the rotation rate of the planet.

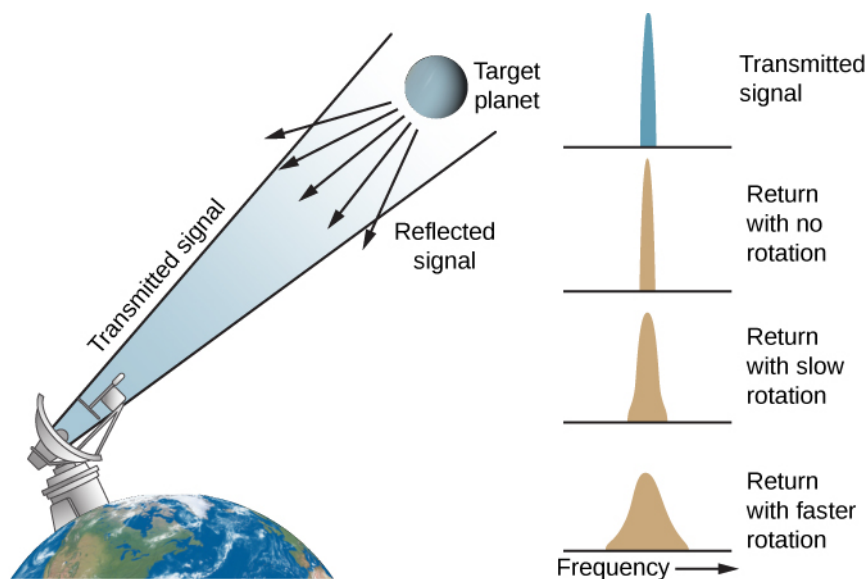


Figure 9.21 Doppler Radar Measures Rotation. When a radar beam is reflected from a rotating planet, the motion of one side of the planet's disk toward us and the other side away from us causes Doppler shifts in the reflected signal. The effect is to cause both a redshift and a blueshift, widening the spread of frequencies in the radio beam.

Mercury's period of rotation (how long it takes to turn with respect to the distant stars) is 59 days, which is just two-thirds of the planet's period of revolution. Subsequently, astronomers found that a situation where the spin and the orbit of a planet (its year) are in a 2:3 ratio turns out to be stable. (See [What a Difference a Day Makes](#) for more on the effects of having such a long day on Mercury.)

Mercury, being close to the Sun, is very hot on its daylight side; but because it has no appreciable atmosphere, it gets surprisingly cold during the long nights. The temperature on the surface climbs to 700 K (430 °C) at noontime. After sunset, however, the temperature drops, reaching 100 K (-170 °C) just before dawn. (It is even colder in craters near the poles that receive no sunlight at all.) The range in temperature on Mercury is thus 600 K (or 600 °C), a greater difference than on any other planet.

MAKING CONNECTIONS



What a Difference a Day Makes

Mercury rotates three times for each two orbits around the Sun. It is the only planet that exhibits this relationship between its spin and its orbit, and there are some interesting consequences for any observers who might someday be stationed on the surface of Mercury.

Here on Earth, we take for granted that days are much shorter than years. Therefore, the two astronomical ways of defining the local “day”—how long the planet takes to rotate and how long the Sun takes to return to the same position in the sky—are the same on Earth for most practical purposes. But this is not the case on Mercury. While Mercury rotates (spins once) in 59 Earth days, the time for the Sun to return to the same place in Mercury’s sky turns out to be two Mercury years, or 176 Earth days. (Note that this result is not intuitively obvious, so don’t be upset if you didn’t come up with it.) Thus, if one day at noon a Mercury explorer suggests to her companion that they should meet at noon the next day, this could mean a very long time apart!

To make things even more interesting, recall that Mercury has an eccentric orbit, meaning that its distance from the Sun varies significantly during each mercurian year. By Kepler’s law, the planet moves fastest in its orbit when closest to the Sun. Let’s examine how this affects the way we would see the Sun in the sky during one 176-Earth-day cycle. We’ll look at the situation as if we were standing on the surface of Mercury in the center of a giant basin that astronomers call Caloris ([Figure 9.23](#)).

At the location of Caloris, Mercury is most distant from the Sun at sunrise; this means the rising Sun looks smaller in the sky (although still more than twice the size it appears from Earth). As the Sun rises higher and higher, it looks bigger and bigger; Mercury is now getting closer to the Sun in its eccentric orbit. At the same time, the apparent motion of the Sun slows down as Mercury’s faster motion in orbit begins to catch up with its rotation.

At noon, the Sun is now three times larger than it looks from Earth and hangs almost motionless in the sky. As the afternoon wears on, the Sun appears smaller and smaller, and moves faster and faster in the sky. At sunset, a full Mercury year (or 88 Earth days after sunrise), the Sun is back to its smallest apparent size as it dips out of sight. Then it takes another Mercury year before the Sun rises again. (By the way, sunrises and sunsets are much more sudden on Mercury, since there is no atmosphere to bend or scatter the rays of sunlight.)

Astronomers call locations like the Caloris Basin the “hot longitudes” on Mercury because the Sun is closest to the planet at noon, just when it is lingering overhead for many Earth days. This makes these areas the hottest places on Mercury.

We bring all this up not because the exact details of this scenario are so important but to illustrate how many of the things we take for granted on Earth are not the same on other worlds. As we’ve mentioned before, one of the best things about taking an astronomy class should be ridding you forever of any “Earth chauvinism” you might have. The way things are on our planet is just one of the many ways nature can arrange reality.

The Surface of Mercury

The first close-up look at Mercury came in 1974, when the US spacecraft Mariner 10 passed 9500 kilometers

from the surface of the planet and transmitted more than 2000 photographs to Earth, revealing details with a resolution down to 150 meters. Subsequently, the planet was mapped in great detail by the MESSENGER spacecraft, which was launched in 2004 and made multiple flybys of Earth, Venus, and Mercury before settling into orbit around Mercury in 2011. It ended its life in 2015, when it was commanded to crash into the surface of the planet.

Mercury's surface strongly resembles the Moon in appearance (**Figure 9.22** and **Figure 9.23**). It is covered with thousands of craters and larger basins up to 1300 kilometers in diameter. Some of the brighter craters are rayed, like Tycho and Copernicus on the Moon, and many have central peaks. There are also *scarps* (cliffs) more than a kilometer high and hundreds of kilometers long, as well as ridges and plains.

MESSENGER instruments measured the surface composition and mapped past volcanic activity. One of its most important discoveries was the verification of water ice (first detected by radar) in craters near the poles, similar to the situation on the Moon, and the unexpected discovery of organic (carbon-rich) compounds mixed with the water ice.

LINK TO LEARNING



Scientists working with data from the **MESSENGER mission** (<https://openstax.org/l/30MESSmercuryrt>) put together a rotating globe of Mercury, in false color, showing some of the variations in the composition of the planet's surface. You can watch it spin.

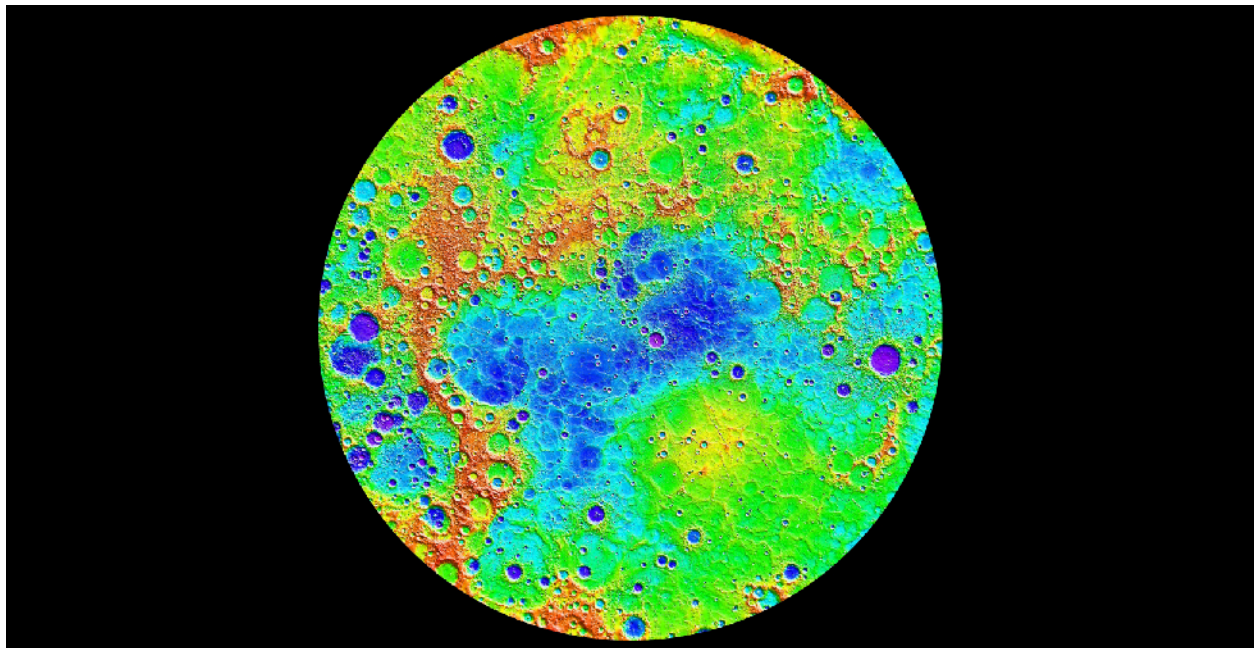


Figure 9.22 Mercury's Topography. The topography of Mercury's northern hemisphere is mapped in great detail from MESSENGER data. The lowest regions are shown in purple and blue, and the highest regions are shown in red. The difference in elevation between the lowest and highest regions shown here is roughly 10 kilometers. The permanently shadowed low-lying craters near the north pole contain radar-bright water ice. (credit: modification of work by NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

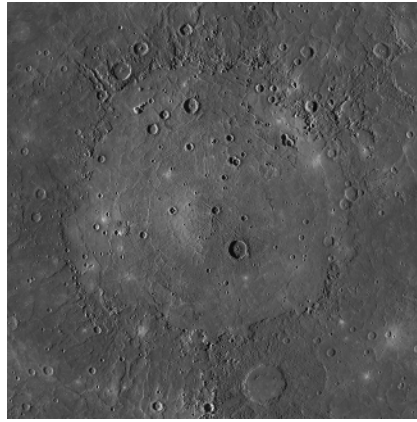


Figure 9.23 Caloris Basin. This partially flooded impact basin is the largest known structural feature on Mercury. The smooth plains in the interior of the basin have an area of almost two million square kilometers. Compare this photo with [Figure 9.11](#), the Orientale Basin on the Moon. (credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington)

Most of the mercurian features have been named in honor of artists, writers, composers, and other contributors to the arts and humanities, in contrast with the scientists commemorated on the Moon. Among the named craters are Bach, Shakespeare, Tolstoy, Van Gogh, and Scott Joplin.

There is no evidence of plate tectonics on Mercury. However, the planet's distinctive long scarps can sometimes be seen cutting across craters; this means the scarps must have formed later than the craters ([Figure 9.24](#)). These long, curved cliffs appear to have their origin in the slight compression of Mercury's crust. Apparently, at some point in its history, the planet shrank, wrinkling the crust, and it must have done so after most of the craters on its surface had already formed.

If the standard cratering chronology applies to Mercury, this shrinkage must have taken place during the last 4 billion years and not during the solar system's early period of heavy bombardment.



Figure 9.24 Discovery Scarp on Mercury. This long cliff, nearly 1 kilometer high and more than 100 kilometers long, cuts across several craters. Astronomers conclude that the compression that made "wrinkles" like this in the planet's surface must have taken place after the craters were formed. (credit: modification of work by NASA/JPL/Northwestern University)

The Origin of Mercury

The problem with understanding how Mercury formed is the reverse of the problem posed by the composition of the Moon. We have seen that, unlike the Moon, Mercury is composed mostly of metal. However, astronomers think that Mercury should have formed with roughly the same ratio of metal to silicate as that found on Earth or Venus. How did it lose so much of its rocky material?

The most probable explanation for Mercury's silicate loss may be similar to the explanation for the Moon's lack of a metal core. Mercury is likely to have experienced several giant impacts very early in its youth, and one or more of these may have torn away a fraction of its mantle and crust, leaving a body dominated by its iron core.

LINK TO LEARNING



You can follow some of [NASA's latest research on Mercury \(https://openstax.org//30NASAresmercu\)](https://openstax.org//30NASAresmercu) and see some helpful animations on the MESSENGER web page.

Today, astronomers recognize that the early solar system was a chaotic place, with the final stages of planet formation characterized by impacts of great violence. Some objects of planetary mass have been destroyed, whereas others could have fragmented and then re-formed, perhaps more than once. Both the Moon and Mercury, with their strange compositions, bear testimony to the catastrophes that must have characterized the solar system during its youth.