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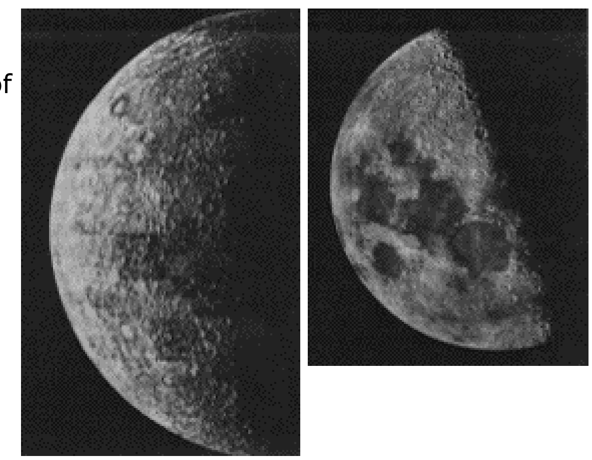
Sun-Scorched Mercury

For centuries, people knew little about Mercury, the first planet out from the Sun. Its small size — 4878 kilometers (3030 miles) in diameter, a little over 1/3 the size (38%) of Earth — and nearness to the Sun made it difficult to observe. A visit from the unmanned spacecraft *Mariner 10* in 1974 opened the door to a better understanding of the second smallest planet (after Pluto) in the solar system.

What does Mercury look like?

At first glance, Mercury looks just like the Moon. Its surface is covered with craters, remnants of a period early in the solar system's history when rocky debris left over from the formation of the planets rained down on the young planets and moons, gouging out huge craters on impact. The largest impact crater found by *Mariner 10,* the Caloris Basin (from the Latin word for "hot''), 1300 kilometers (800 miles) across, looks much like Mare Orientale on the Moon, with concentric rings of cliffs formed by the impact. Mercury's craters are named after artists, writers, composers and others who have contributed to the arts and humanities, to complement the naming of lunar craters after scientists. Prominent "Mercurian'' craters include Bach, Shakespeare, Tolstoy, Mozart, and Goethe.



Left: Photomosaic of Mercury taken by approaching Mariner 10. (Courtesy NASA) **Right:** The Moon at first quarter. (Courtesy Lick Observatory)

But Mercury has one distinctive non-lunar feature — numerous cliffs, hundreds of miles long, called *scarps*. Some rise three kilometers (two miles) above the planet's surface. The scarps probably formed when Mercury's interior shrank by a few kilometers as it cooled and solidified, causing the planet's crust to wrinkle, much like the skin of a drying raisin. The scarps are named after famous sailing ships, for example, Endeavor (Captain Cook's ship), Santa Maria (Columbus' flagship), and Victoria (the first ship to sail around the world, from 1519 to 1522, under the command of Magellan and his successors).

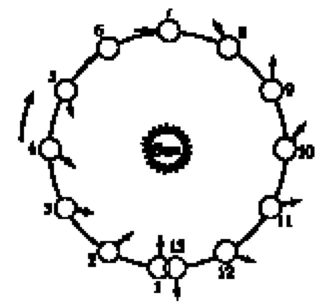
What is Mercury like on the inside?

Like the Earth, Mercury has an iron core. But Mercury's core occupies proportionately more (3/4) of the planet's diameter than Earth's does (about half). You can think of Mercury as a metal ball the size of the Moon surrounded by about 700 kilometers (430 miles) of rocky crust. The large relative size of Mercury's core makes it the most iron-rich planet in the solar system, with iron accounting for 65-70% of the planet's mass. Mercury's abundance of iron resulted from its position near the Sun. When the planets were forming out of the same cloud of gas and dust as the Sun, the temperatures in the warm inner regions of the primordial solar nebula were so high that iron-rich minerals were just about the only ones that could condense into solids. Farther away from the Sun, other minerals could also condense. Thus the iron content of the rocky planets in the solar system decreases with increasing distance from the Sun.

Mercury's iron core may also be responsible for one of the most surprising findings from *Mariner 10* — the planet's weak magnetic field, 100 times weaker than Earth's. Astronomers and geologists are still trying to figure out what causes Mercury's field. In the case of the Earth, rapid rotation of its molten iron core generates electrical currents which produce the Earth's magnetic field. But Mercury is so small, astronomers had assumed its core had cooled and solidified. Plus, it rotates too slowly to generate a magnetic field the way the Earth does. Or so they thought. Perhaps Mercury's core is still partially liquid, or perhaps the magnetic field is "left over'' from an earlier time when the iron core was molten. Astronomers continue to work on this puzzle.

Does Mercury keep the same side facing the Sun, as the Moon does to the Earth?

Because of Mercury's small size and nearness to the Sun, astronomers on Earth can see only a few faint, hazy markings on its surface. Studies of these indistinct markings led them to think Mercury always kept the same side facing the Sun. The other side of the planet would then never see the light of day.



During each revolution around the Sun, Mercury rotates 1 1/2 times on its axis. For every two complete orbits of the Sun, Mercury rotates three times about it axis, a so-called spin-orbit coupling. (Adapted from Universe, 3rd edition, by William J. Kaufmann III, Published by W. H. Freeman and Co., 1991).

In the mid-1960s, scientists bounced radar waves off of Mercury. The reflected signals came back shifted slightly in wavelength from those sent, proof that Mercury was rotating on its axis. Radar signals reflected off the side of the planet spinning toward the Earth were shifted to slightly shorter wavelengths, those that bounced off the side spinning away from the Earth were shifted to slightly longer wavelengths. These shifts are called *Doppler shifts,* and are analogous to the shift in pitch of a police siren as it approaches, passes and moves away from you. Because of the shifts, the radar signals bounced off Mercury came back spread out over a small wavelength range. From the width of the spread, astronomers calculated Mercury's rotation speed. They found it takes 59 days for Mercury to complete one rotation.

Italian physicist Giuseppe Colombo noticed that 59 days is exactly 2/3 of the 88 days it takes Mercury to complete one revolution around the Sun. Thus Mercury makes three complete rotations on its axis for every two complete orbits around the Sun (see figure below), which means it does not always keep the same side facing the Sun (in which case the number of rotations would exactly equal the number of revolutions). The earlier astronomers were wrong.

After it first flew past Mercury, *Mariner 10* went into an orbit around the Sun that brings it back to the small planet every two Mercurian years (176 days). During its second and third fly-bys, the spacecraft sent pictures that showed the same side of Mercury was facing the Sun as on its first approach. This confirmed the 3:2 ratio of Mercury's rotation and orbit around the Sun, but, unfortunately, also meant that *Mariner 10* photographed the same craters each time it passed by. After three fly-bys, the spacecraft ran out of gas for the small rockets that control where it points its cameras, and, even though it continues to pass near Mercury every few months, it can no longer take photographs of the planet or send them back to Earth.

Mercury's slow rotation has an unusual effect on the Sun's apparent motion through the Mercurian sky. Mercury has the most elliptical (non-circular) orbit of any planet except Pluto, with a distance from the Sun that varies from 46 million kilometers (29 million miles) at its closest (*(perihelion*) to 70 million kilometers (43 million miles) at its furthest (*aphelion*). Because of this eccentricity, Mercury's speed along its orbit varies from a high of 59 kilometers/second (37 miles/second) near perihelion to a low of 39 kilometers/second (24 miles/second) at aphelion. An astronaut standing on Mercury would see the Sun rise in the east and set in the west, just as it does on Earth . But, when the planet is near perihelion in its orbit, its rapid motion around the Sun is faster than its leisurely rotation about its axis (which does not vary at different places in the orbit). At this time, an astronaut would see the Sun stop its motion through the sky and move backward (west to east) for a few Earth days before resuming its normal motion. Someone watching sunset on Mercury when the planet was near perihelion would see the Sun dip below the western horizon, and then come back up, only to set again an Earth day or two later.

Does Mercury have an atmosphere?

Scientists had always thought that Mercury was too small and too hot to hold onto any kind of atmosphere. During a Mercurian day, any atoms or molecules of gas in an atmosphere would be heated so much that they would gain enough energy to escape the tiny planet's weak gravity. *Mariner 10* didn't detect any atmosphere during its visits.

Ten years after *Mariner 10,* astronomers studying Mercury from Earth discovered that the planet does indeed have an extremely thin atmosphere, less dense than any vacuum on Earth, composed primarily of sodium and potassium atoms. Astronomers originally thought the sodium was ejected from surface rocks into the "atmosphere'' when particles from the Sun or meteorites hit the surface. Newer observations, which show that sodium and potassium readings are enhanced when the Caloris Basin is in view, indicate that the tenuous atmosphere may have somehow "diffused'' up through the planet's crust. Research on the puzzle of Mercury's atmosphere is continuing.

What is the temperature of Mercury?

At noon, on the equator, the temperature of Mercury climbs to 800 degrees F, hot enough to melt a soda pop can. But, since there is no appreciable atmosphere to retain the heat, the temperature falls to -280 degrees F at night. This nearly 1100 degrees F "daily'' temperature swing is the largest of any planet in the solar system.

Because Mercury's rotation and revolution are locked in a 3:2 relationship, a Mercurian day, from noon to succeeding noon, actually lasts 176 Earth days ("noon'' refers to the time when the Sun is directly overhead for someone standing on the planet's surface). The 59-day rotation period mentioned earlier refers to the planet's rotation relative to the background stars. That corresponds, in the figure at left, to Mercury's motion from position 1 (noon) to position 9, when the arrow is again pointed in the same direction as in position 1. But, because of Mercury's orbital motion, at position 9, the arrow is not pointing back at the Sun, which would indicate the next Mercurian noon. After one complete orbit around the Sun, position 13, the arrow points directly away from the Sun (midnight). Another full orbit around the Sun (a second 88 Earth days) is needed to bring the arrow back to its original "noon'' position, pointing directly at the Sun. Astronauts living on Mercury would find themselves alternately fried for 88 Earth days, as the Sun slowly moves across the sky, and frozen for 88 Earth days during the long Mercurian night.

Activity Corner

Editor's Note: Ken Willcox, a member of the ASP Board of Directors, has developed this activity to give students a sense of the scale of the solar system and the immense distances between stars. While there are many activities dealing with a solar system scale, we especially liked Ken's conversational style and his emphasis on finding local landmarks to help students grasp the distances. If you have developed an activity that students enjoy, send a write-up of the activity to: Teachers Newsletter Activities, ASP, 390 Ashton Avenue, San Francisco, CA 94112, and, if appropriate, we will publish it in a future edition of the newsletter.

Summary:

People cannot fully comprehend astronomical distances. Since we don't really relate to distances greater than we ourselves have traveled, this exercise rescales our Solar System's distances, based on the Earth being the size of a ping-pong ball (1.5"). On this scale, the speed of light (186,000 miles/second) becomes a slow walk (2.1 miles/ hour) and the planets the size of familiar objects like a beach ball (Jupiter), basketball (Saturn), softball (Neptune and Uranus), and marble (Pluto and Mercury). By allowing students to picture themselves walking out of the solar system, we can let them "experience'' its actual size rather than memorize diameters and distances.

Preparation:

Before doing the activity with a class, find a road in your town that follows as straight an east-west line as possible. Find a prominent landmark on that road — major intersection, well known building, etc. — for the position of the Earth. With a map, or, better yet, driving in your car, find other landmarks along the road that students will recognize at close to the distances for the planets given in the table on the next page. The idea is to provide landmarks to help the students visualize the relative distances traveled. If you live in the midwestern or eastern U.S., line the planets up east to west, starting at the Sun. If you live in the western U.S., line the planets up west to east, in order to have major cities to act as landmarks. The following description is one I use from my home town of Bartlesville, Oklahoma.

If you are taking a group out to an observing session, this is an interesting presentation to make on the way, explaining that the bus or van (your spaceship) is now going to proceed at the speed of light (2.1 miles/hour) out of the solar system. Of course you will probably want to go ten times the speed of light ("warp 10''), 21 miles/hour or faster, in order to get to your destination. You can then point out where the planets would be along the way using the odometer of the bus.

Procedure:

Start by telling your students that they are going to take a journey at the speed of light from our Earth, which we have compressed to the size of a ping-pong ball. Show the students a ping-pong ball, or better yet, give them one to take home. The Sun will be east of our Earth almost five football fields away (488 yards). It would be almost 14 feet (13.6') in diameter, about the size of a large weather balloon. Most classrooms have 10' or 12' ceilings, so it probably wouldn't quite fit in the classroom.

"As we walk west from the Sun, we come to the first planet in the solar system, which is...?'' Let the students answer rather than telling them. Get them involved mentally, but most importantly get them seeing themselves walking along the same road you are describing. "Mercury!''... "Yes, that's right, and Mercury would be about three football fields east of our Earth and the size of a small marble (0.5").'' Hold up a small marble.

"Continuing to walk west, the next planet you would arrive at is...?'' Always let the students tell you the planet if they answer promptly (I wait five or six seconds), but don't let the activity become a test or slow down too much. "Venus!''. . . "That's right, and Venus would be 1/3 football fields to the east of our Earth and about the same size; in other words, another ping-pong ball.'' You can have a blue ping-pong ball for the Earth and a yellow or white one for Venus.

"Finally we arrive at our Earth and ... oh yes, I forgot to tell you that if the Earth is the size of a ping-pong ball, the speed of light is 2.1 miles/hour.'' Few students will be able to visualize 2.1 mph, so show them by placing the ping-pong ball that represents Earth down on a desk or table where each student can clearly see it. Explain that you are in a spaceship moving at the speed of light as you slowly walk past the ping-pong ball.

"As we continue our journey out of the solar system, we cannot move faster than 2.1 miles/hour because nothing that has mass can move faster than the speed of light. We continue walking west 2 1/2 football fields, about where the hospital (use landmark) is, where we will find the next planet, which is...? Mars, the red planet, is just a little more than half the size of our ping-pong-ball Earth sitting back at the intersection (Earth landmark).''

"Continuing west we come to the largest planet in the solar system...?'' "Jupiter!'' "Correct, and Jupiter is the size of a beach ball (16.8").'' Use your hands to hold up an imaginary beach ball, or use a 16" or 17" one. "Jupiter will be sitting in the middle of the road at the river (specify a landmark) 1.2 miles west of our ping-pong-ball Earth.'' The distance described in miles will not have much meaning at this point and only landmarks should be used to describe positions of the planets beyond Jupiter.

Using landmarks at the appropriate distances (see table), have the students imagine walking past Saturn (the size of a basketball), Uranus and Neptune (both softballs), and Pluto (a small marble, about the size of the end of your little finger). Depending on the time available, you can also ask the students how long they think it would take them to walk at the speed of light from the Earth (at the intersection, or other major landmark) to Saturn or any of the other planets (see table for times).

"Now we are to the edge of our solar system. How much farther west must we walk before we get to the nearest star (4.3 light years away)?'' Let the students call out cities west of your location. Most will usually pick the nearest town, which may be only 10 or 20 miles away. Get them talking at this point so they are deeply involved in the activity. They must see themselves walking west on the road you have selected.

"No, keep walking.'' Now they will probably pick the next nearest town, which may be at the limiting edge of their geographical knowledge. Don't let the activity become a geography test or slow down here. Instead offer cities west of your location, and, when they appear to be out of ideas, you take over and guide them on the journey which will go something like the following.

"You continue walking west to Albuquerque, New Mexico, then through Flagstaff, Arizona. You finally get to Los Angeles, California.'' Pause for just a second to give the students the idea that the nearest star would be all the way to the west coast! Then continue with... "you must now get in a small boat and row across the Pacific Ocean at 2.1 miles/hour. You pass the islands of Hawaii and wave as you go by, but you continue rowing all the way to China.'' Pause for a couple of seconds. "You get out of the boat and take a slow train across Asia and change to a slow camel that moves at 2.1 miles/hour across Africa where you get into another boat and row across the Atlantic Ocean all the way back to New York City. You get out of the boat and walk all the way back home (Bartlesville, Oklahoma for me)...'' Pause for a second before saying, "You still have two more trips around the Earth before you get to the nearest star!''

It is very important to describe the trip in just enough detail to give a vivid picture of them walking and rowing around the world. At this point your students should be wide-eyed and uttering things like, "Wow, golly, neat!''

Planet	**Diameter miles**	**Relative Diameter**	**Solar Distance million miles**	**Relative Distance (if Earth were a ping-pong ball)**	
				Distance	Time from Earth at speed of light
Sun	864,000	13.6'	———	488 yd	7.9 min
Mercury	2,900	0.5"	36	300 yd	4.8 min
Venus	7,700	1.5"	67	137 yd	2.2 min
Earth	7,927	1.5"	93	——	———
Mars	4,200	0.8"	142	252 yd	4.1 min
Jupiter	88,700	16.8"	484	1.2 mi	35 min
Saturn	75,100	14.2"	887	2.4 mi	1 hr 9 min
Uranus	29,600	5.5"	1,784	5.1 mi	2 hr 26 min
Neptune	27,600	5.2"	2,795	8.1 mi	3 hr 53 min
Pluto	1,800	0.3"	3,668	10.7 mi	7 hr 8 min
Alpha Centauri	——	about 13.0'	——	75,300 mi	4.3 yr

Speed of light = 2.1 miles/hour if the Earth is the size of a ping-pong ball. If the Earth were the size of a ping-pong ball (1.5"), the nearest star (Alpha Centauri) would be more than three times (3.02) the Earth's circumference away from the Sun and the fastest you could approach it would be at a slow walk (2.1 miles/hour).