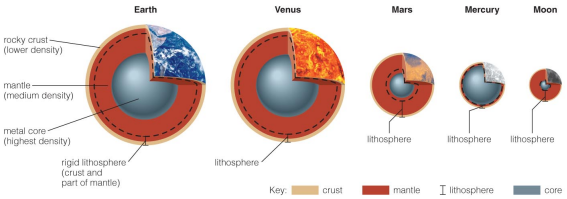
Jorge Ramirez
Instructor of Mathematics, Physics & Astronomy

ASTRONOMY

Chapter 9 CRATERED WORLDS
PowerPoint Image Slideshow

openstax™

Recap:



- Applying what we have learned about Earth's interior to other planets tells us what their interiors are probably like.

Thought Question

What cools off faster?

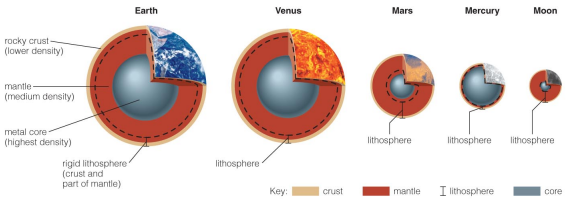
A. A grande-size cup of Starbucks coffee
B. A teaspoon of cappuccino in the same cup

Thought Question

What cools off faster?

A. A big terrestrial planet
B. A tiny terrestrial planet

Size & Interior Cooling



- Smaller worlds cool off faster and harden earlier.
- The Moon and Mercury are now geologically "dead."

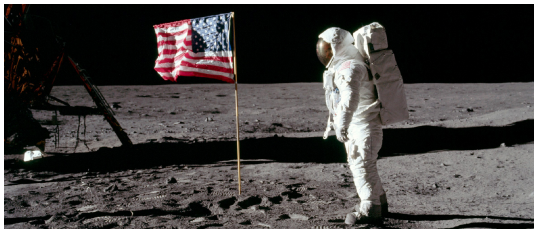
9.1 GENERAL PROPERTIES OF THE MOON

- Craters & Smooth plains
- Diameter 3476 km
- Gravity 17% of Earth
- Density 3.3 g/cm3
- Surface Area 27% of Earth

Exploration

- Russia Luna 1960's
- Apollo 1968-1972 (9 piloted spacecraft)
- 1969 (1st of 6 landings)

Exploration of the Moon



- **Apollo 11 Astronaut Edwin "Buzz" Aldrin on the Surface of the Moon.** Because there is no atmosphere, ocean, or geological activity on the Moon today, the footprints you see in the image will likely be preserved in the lunar soil for millions of years (credit: modification of work by NASA/ Neil A. Armstrong).

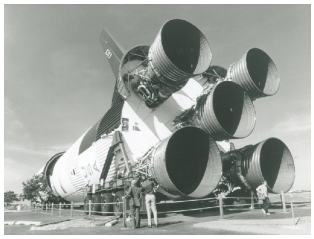
Figure 9.3

- **Scientist on the Moon.** Geologist (and later US senator) Harrison "Jack" Schmitt in front of a large boulder in the Littrow Valley at the edge of the lunar highlands. Note how black the sky is on the airless Moon. No stars are visible because the surface is brightly lit by the Sun, and the exposure therefore is not long enough to reveal stars.

Composition and Structure

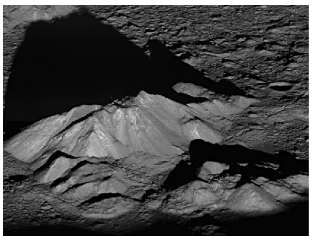
- **Handling Moon Rocks.** Lunar samples collected in the Apollo Project are analyzed and stored in NASA facilities at the Johnson Space Center in Houston, Texas. Here, a technician examines a rock sample using gloves in a sealed environment to avoid contaminating the sample. (credit: NASA JSC)

Figure 9.5



- **Moon Rocket on Display.** One of the unused Saturn 5 rockets built to go to the Moon is now a tourist attraction at NASA's Johnson Space Center in Houston, although it has been moved indoors since this photo was taken. (credit: modification of work by David Morrison)

9.2 THE LUNAR SURFACE



- **Sunrise on the Central Mountain Peaks of Tycho Crater, as Imaged by the NASA Lunar Reconnaissance Orbiter.** Tycho, about 82 kilometers in diameter, is one of the youngest of the very large lunar craters. The central mountain rises 12 kilometers above the crater floor. (credit: modification of work by NASA/Goddard/Arizona State University)

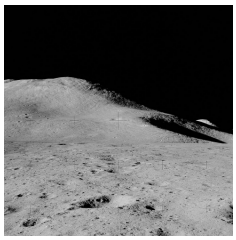
Figure 9.2

- **Two Sides of the Moon.** The left image shows part of the hemisphere that faces Earth; several dark maria are visible. The right image shows part of the hemisphere that faces away from Earth; it is dominated by highlands. The resolution of this image is several kilometers, similar to that of high-powered binoculars or a small telescope. (credit: modification of work by NASA/GSFC/Arizona State University)

Figure 9.7

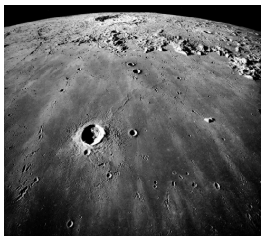
- **Lunar Highlands.** The old, heavily cratered lunar highlands make up 83% of the Moon's surface. (credit: Apollo 11 Crew, NASA)

Figure 9.8



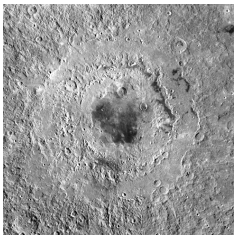
- **Lunar Mountain.** This photo of Mt. Hadley on the edge of Mare Imbrium was taken by Dave Scott, one of the Apollo 15 astronauts. Note the smooth contours of the lunar mountains, which have not been sculpted by water or ice. (credit: NASA/Apollo Lunar Surface Journal)

Figure 9.9



- **Lunar Maria.** About 17% of the Moon's surface consists of the maria—flat plains of basaltic lava. This view of Mare Imbrium also shows numerous secondary craters and evidence of material ejected from the large crater Copernicus on the upper horizon. Copernicus is an impact crater almost 100 kilometers in diameter that was formed long after the lava in Imbrium had already been deposited. (credit: NASA, Apollo 17)

Figure 9.11



- **Mare Orientale.** The youngest of the large lunar impact basins is Orientale, formed 3.8 billion years ago. Its outer ring is about 1000 kilometers in diameter, roughly the distance between New York City and Detroit, Michigan. Unlike most of the other basins, Orientale has not been completely filled in with lava flows, so it retains its striking "bull's-eye" appearance. It is located on the edge of the Moon as seen from Earth. (credit: NASA)

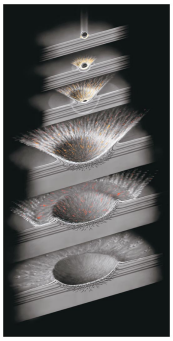
Figure 9.12

- **Footprint on Moon Dust.** Apollo photo of an astronaut's boot print in the lunar soil. (credit: NASA)

Figure 9.17

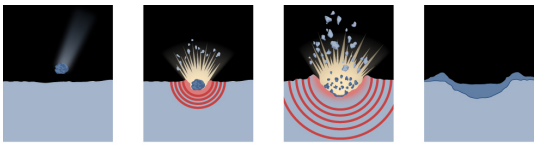
- **The Moon Crossing the Face of Earth.** In this 2015 image from the Deep Space Climate Observatory spacecraft, both objects are fully illuminated, but the Moon looks darker because it has a much lower average reflectivity than Earth. (credit: modification of work by NASA, DSCOVR EPIC team)

9.3 IMPACT CRATERS



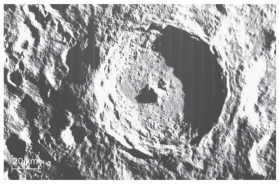
- Most cratering happened soon after the solar system formed.
- Craters are about 10 times wider than the objects that made them.
- Small craters greatly outnumber large ones.

Figure 9.14



- **Stages in the Formation of an Impact Crater.**
(a) The impact occurs.
(b) The projectile vaporizes and a shock wave spreads through the lunar rock.
(c) Ejecta are thrown out of the crater.
(d) Most of the ejected material falls back to fill the crater, forming an ejecta blanket.

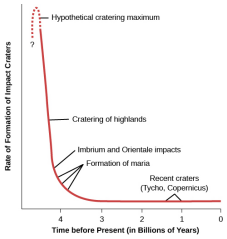
Impact Craters



Meteor Crater (Arizona)

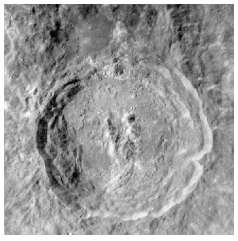
Tycho (Moon)

Figure 9.19



- **Cratering Rates over Time.** The number of craters being made on the Moon's surface has varied with time over the past 4.3 billion years.

Figure 9.15



- **Typical Impact Crater.** King Crater on the far side of the Moon, a fairly recent lunar crater 75 kilometers in diameter, shows most of the features associated with large impact structures. (credit: NASA/JSC/Arizona State University)

Figure 9.13

- **Volcanic and Impact Craters.** Profiles of a typical terrestrial volcanic crater and a typical lunar impact crater are quite different.

Figure 9.16

- **Appearance of the Moon at Different Phases.**
  (a) Illumination from the side brings craters and other topographic features into sharp relief, as seen on the far left side.
  (b) At full phase, there are no shadows, and it is more difficult to see such features. However, the flat lighting at full phase brings out some surface features, such as the bright rays of ejecta that stretch out from a few large young craters. (credit: modification of work by Luc Viatour)

Was there ever geological activity

- Some volcanic activity 3 billion years ago must have flooded lunar craters, creating *lunar maria*.
- The Moon is now geologically dead.

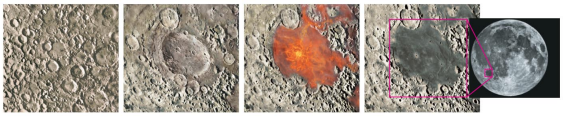


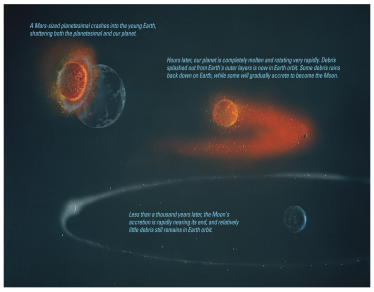
Figure 9.10

- **Rock from a Lunar Mare.** In this sample of basalt from the mare surface, you can see the holes left by gas bubbles, which are characteristic of rock formed from lava. All lunar rocks are chemically distinct from terrestrial rocks, a fact that has allowed scientists to identify a few lunar samples among the thousands of meteorites that reach Earth. (credit: modification of work by NASA)

9.4 THE ORIGIN OF THE MOON

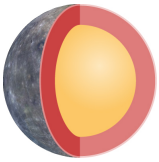
- Our Moon is to large to be captured
- We can rule out that they formed simultaneously or they would have accreted from planetesimals of similar composition and density
- Result from giant impact between Earth and huge planetesimal
  - Giant impact blasted Earth's outer layers into orbit
  - Then accreted into the Moon

Giant Impact



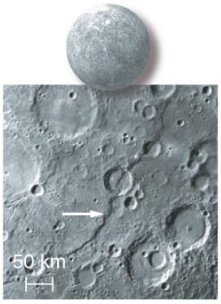
- Simulations indicate Mars size planetesimals.
- Moons over all composition is similar to Earth's outer layers.
- Moon has smaller proportions of easily vaporized ingredients (water).

9.5 MERCURY



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

Mercury

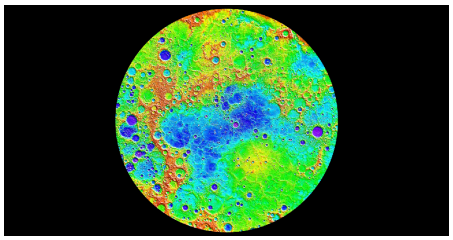


- Distance from Sun: .39 AU
- Period of rotation(day): 59 days
- Revolution period (year): 88 days
- Temperature: night -270 F, day 800 F

Exploration

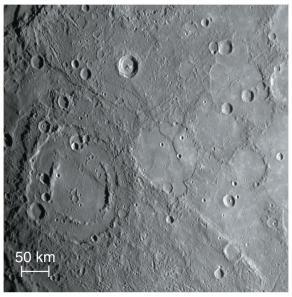
- 1974 Mariner 10
- 2011 Messenger

Figure 9.22



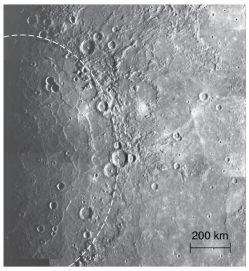
- **Mercury's Topography.** The topography of Mercury's northern hemisphere is mapped in great detail from MESSENGER data. The lowest regions are shown in purple and blue, and the highest regions are shown in red. The difference in elevation between the lowest and highest regions shown here is roughly 10 kilometers. The permanently shadowed low-lying craters near the north pole contain radar-bright water ice.

Cratering of Mercury

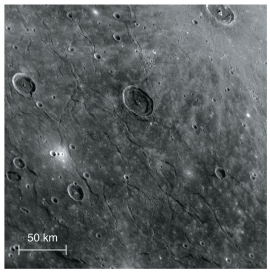


- Mercury has a mixture of heavily cratered and smooth regions like the Moon.
- The smooth regions are likely ancient lava flows.

Cratering of Mercury

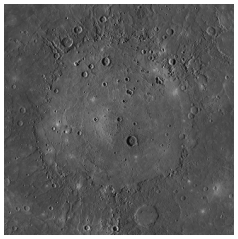


The Caloris Basin is the largest impact crater on Mercury.



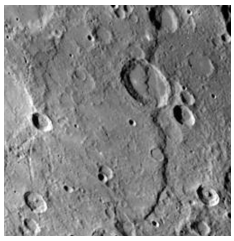
Region opposite the Caloris Basin is jumbled from seismic energy of impact.

Figure 9.23



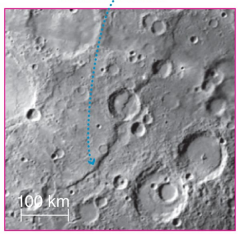
- **Caloris Basin.** This partially flooded impact basin is the largest known structural feature on Mercury. The smooth plains in the interior of the basin have an area of almost two million square kilometers. Compare this photo with **Figure 9.11**, the Orientale Basin on the Moon.

Figure 9.24



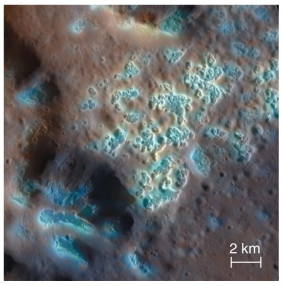
- **Discovery Scarp on Mercury.** This long cliff, nearly 1 kilometer high and more than 100 kilometers long, cuts across several craters. Astronomers conclude that the compression that made "wrinkles" like this in the plank's surface must have taken place after the craters were formed. (credit: modification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

Tectonics on Mercury



- Long cliffs indicate that Mercury shrank early in its history.
- Due to it's large iron core, Mercury retained heat more than the moon causing it to swell.

Recent Geology on Mercury



- Lighter areas (color enhanced) are thought to be "hollows" formed as easily vaporized minerals escape.

Videos

Reading

- 9.1 (optional)
- 9.2
- 9.3
- 9.4
- 9.5