Chapter 7: The Other Terrestrial Planets and Their Comparison to Earth

Mercury ☿

Mass: determined from gravitational influence on comets, the asteroid Icarus (made a close encounter in 1968), and the Mariner 10 spacecraft.

Mass = 3.32×10^{23} Kg ($0.0558\ M_{\oplus}$)

Density = 5.42 grams/cm^3

Orbit:

Eccentricity = 0.21 (2nd most elliptical orbit)

Period = 88 days

Rotation:

Period = 59 days

Mercury has a 3:2 spin-orbit resonance. There are three rotations for every two revolutions. Reason that it is not 1:1 is the highly eccentric orbit.

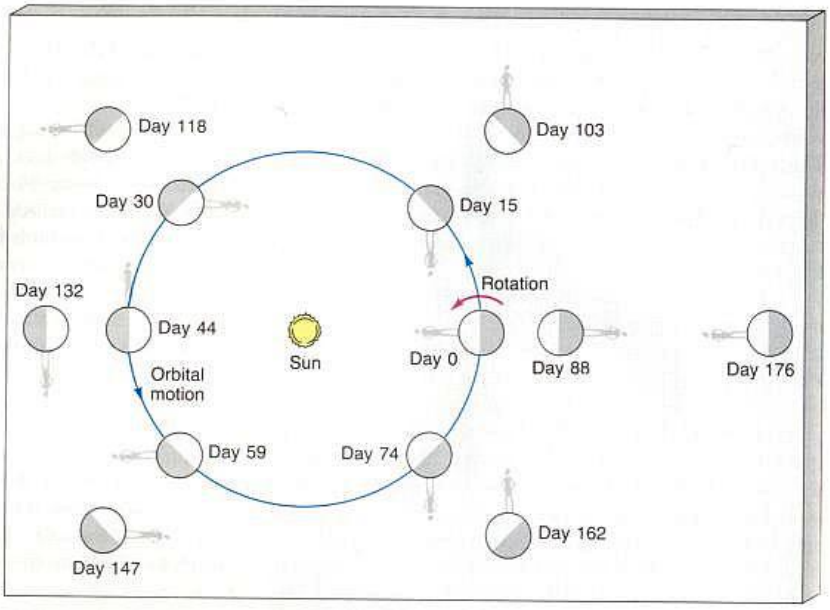


Figure 10.8 *Mercury's orbital and rotational motions combine to produce a day that is 2 years long. The "person" represents an observer standing on the surface of the planet. At Day 0, it is noon for our observer, and the Sun is directly overhead. By the time Mercury has completed one full orbit around the Sun and moved from Day 0 to Day 88, it has rotated on its axis exactly 1.5 times, so that it is now midnight at the observer's location. After another complete orbit, it is noon once again.*

Surface Features:

Very much like the Moon with some major differences.

1. Not as heavily cratered. Extensive intercrater plains (evidence of lava flows).

2. Crater walls not as high and ejecta blankets smaller than on the Moon due to Mercury's higher gravity.

3. Absence of rilles and maria.

4. Many large craters have double walls.

5. Many large scarps (cliffs) indicating the crust has undergone shrinking.

6. Weird terrain: result of the impact that formed the Caloris Planitia.

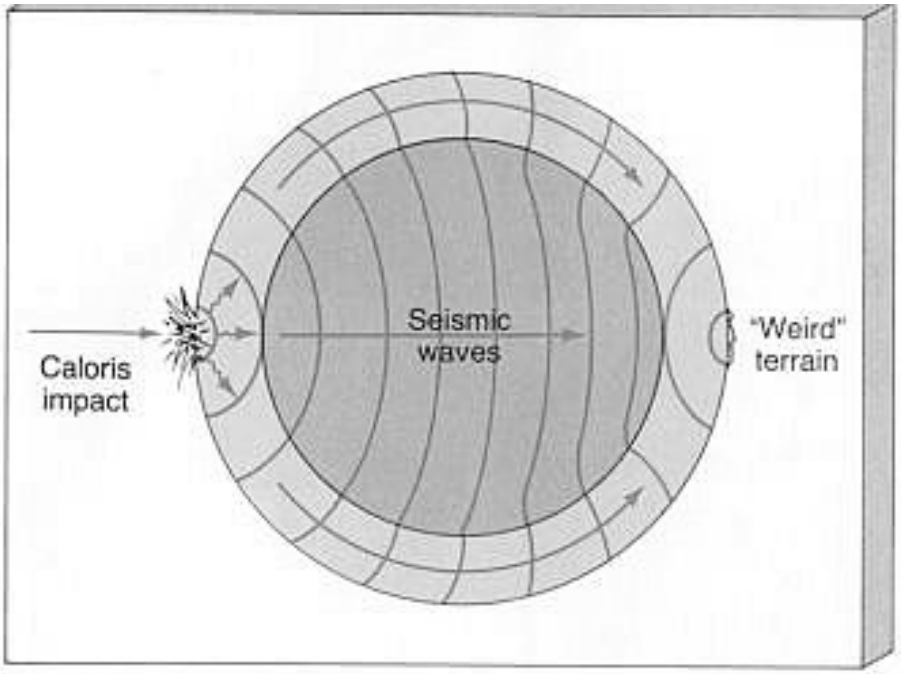


Figure 10.16 *The refocusing of seismic waves after the Caloris basin impact may have created the weird terrain on the opposite side of the planet.*

Magnetic Field and Interior:

A magnetic field 1% as strong as the Earth's magnetic field has been detected.

Possible causes:

1. Remnant magnetism from when Mercury rotated faster and had a molten core.

2. A partially molten core combined with slow rotation produces a weak magnetic field.

Iron core occupies 40% of Mercury's volume or 60% of the planets mass (from magnetic field and high overall density).

Possible causes:

1. High temperature near the Sun prevented lighter materials from condensing.

2. Strong early solar wind stripped the lighter materials from Mercury.

3. Collision with a small planet sized body stripped the planet of its lighter materials.

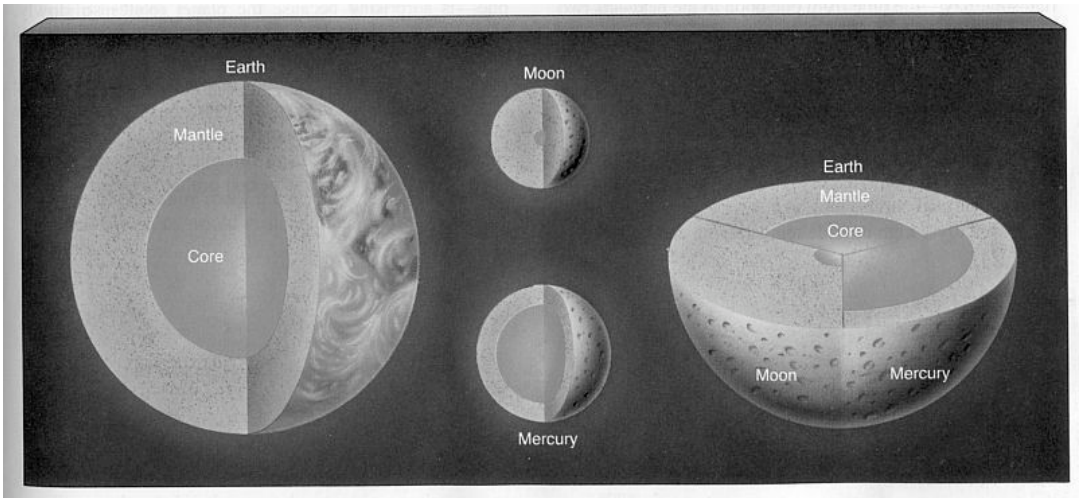


Figure 10.18 *The internal structures of the Earth, the Moon, and Mercury, drawn to the same scale. Note how large a fraction of Mercury's interior is core.*

Atmosphere:

Pseudo atmosphere consists of hydrogen and helium from the solar wind temporarily trapped by its weak gravity, and sodium released by heating of rocks.

Surface Temperatures:

Daytime: 700 Kelvin

Nighttime: 100 Kelvin

Evolutionary History:

1. 4.5 B.Y. At formation Mercury was already depleted of lighter rocky material due to the hotter temperatures in the solar nebula at its location.

2. 4.0 B.Y. Melting and differentiation. Intense bombardment.

3. 3.9 to 3.2 B.Y.? Volcanism erases most craters and the planet cools more slowly that the Moon. Shrinking of crust produces scarps, and geological activity ended sooner than on the Moon.

Concept Test

From Earth Mercury is difficult to observe because it
a) has low albedo.
b) is very dense.
c) is very small.
d) always appears near the Sun.

Venus ♀

Ave. Distance from Sun: 0.72 A.U.

Eccentricity: 0.007 (nearly circular orbit)

Mass: 4.9×10^{24} Kg ($0.82\ M_{\oplus}$)

Density: 5.2 grams/cm^3

Rotation Rate:
The rotation period as determined from ground based radar is 243.01 days in a retrograde direction (from west to east).

Current theory of the retrograde rotation is that Venus was struck by a large body that reversed its rotation.

Atmosphere

Telescopic Observations:
Ground based visual observations do not reveal any structure of the atmosphere. Spectroscopic and infrared observations revealed that it is composed mostly of carbon dioxide with some nitrogen and traces of other gases.

carbon dioxide -	96.5%
nitrogen -	3.5%
water vapor	
carbon monoxide	
sulfuric acid	Traces
sulfur dioxide	
argon	

This chemical composition was later confirmed by space probes

Concept Test

The surface of Venus is mostly low density rock, while the average density of Venus is very similar to that of Earth. The interior is therefore
a) rapidly rotating.
b) composed of low density material.
c) denser than the average density of Earth.
d) homogeneous.

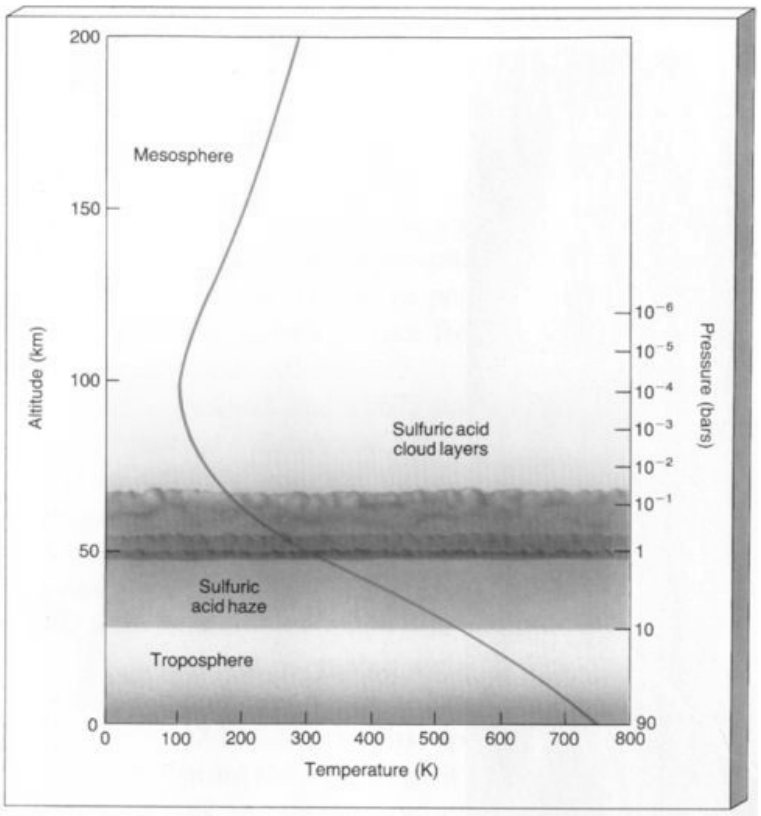


Figure 11.10 *The structure of the atmosphere of Venus, as determined by U.S. and Soviet probes.*

Spacecraft Observations:

Temperature: 750 K or 900 degrees F

Pressure: 90 atmospheres

Greenhouse Effect:

Temperature is due to the presence of carbon dioxide, which retains 99% of the infrared heat reemitted by the planet.

How did this come about?

1. Like the Earth, Venus had a primary atmosphere consisting of volatile gases that escaped the planet's gravitational pull.

2. Secondary atmosphere consisted of carbon dioxide, watervapor, sulfur compounds, and nitrogen compounds.

3. Two possible explanations:

A. The temperature was already high enough to prevent the formation of oceans (Recall that the oceans on the Earth removed the carbon dioxide from the atmosphere) and the full greenhouse effect was already in force.

B. Runaway Greenhouse Effect
Venus formed oceans that removed carbon dioxide from the atmosphere. As the Sun's output increased greenhouse gases were released from its oceans resulting in a runaway greenhouse effect that evaporated its oceans.

Dense water vapor and carbon dioxide created a more severe greenhouse effect in the past. Water molecules were broken up by the Sun's UV radiation resulting in a lessened greenhouse effect.

Atmospheric Circulation:
At the cloud tops the wind speeds blow east to west at about 360 km/hr. Wind speeds decrease to zero toward the surface.

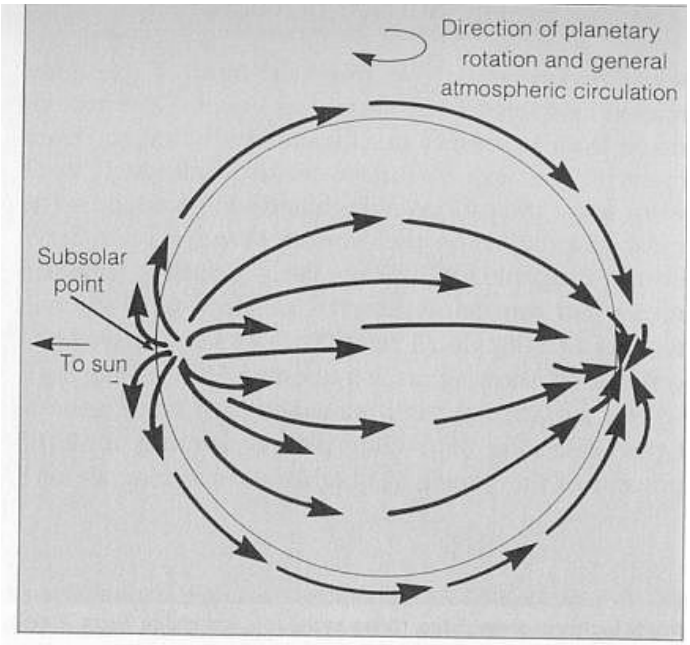


FIG. 9.7. HIGH-ALTITUDE CIRCULATION. Well above the clouds (which are rotating from right to left in this sketch), gases heated at the subsolar point circulate around the planet toward the dark side, where they cool and descend.

Within the cloud layers convection cells circulate gases from the equatorial regions to the polar regions. These cells in turn drive similar circulation patterns above and below the cloud layers.

High altitude circulation: gases heated at the subsolar point (point facing the Sun) rise and circulate to the back side of the planet where they cool and descend. This is possible due to the slow rotation.

Surface Features:

1. Radar mapping from Earth: reveals features about 1.5 km across.

2. Magellan probe (radar): resolution of about 120 meters.

3. Soviet landers: Surface rock compositions.

Topography

Two continent sized features - Ishtar Terra, and Aphrodite Terra.

Two other highlands: Alpha and Beta Regio

Extensive lava flows surround the highlands.

Impact craters - smallest are about 3 km across. Crater numbers are only 1/10 of the lunar maria, which implies an age of 200 to 300 million years.

Volcanism:

1. Most craters are of volcanic origin.

2. Lava domes.

3. Shield volcanoes with their characteristic caldera.

4. Coronae - caused by upwelling mantle material.

5. Fluctuating levels of sulfur dioxide imply active volcanoes.

6. Magellan spacecraft found evidence for young looking lava flows on Maat Mons.

Internal Structure

Probably similar to the Earth's internal structure.

Slow rotation has not produced a dynamo since there is no magnetic field.

Mars ♂

Distance from Sun: 1.52 A.U.

Eccentricity: 0.093 (third most eccentric orbit)

Orbital Period: 1.87 yrs

Mass: 6.42 x 10^{23} Kg (0.107 $M_{\oplus}$)

Density: 3.9 grams/cm^3

Rotation Period: 24.6 hours

Axial Tilt: 25.2^{o}

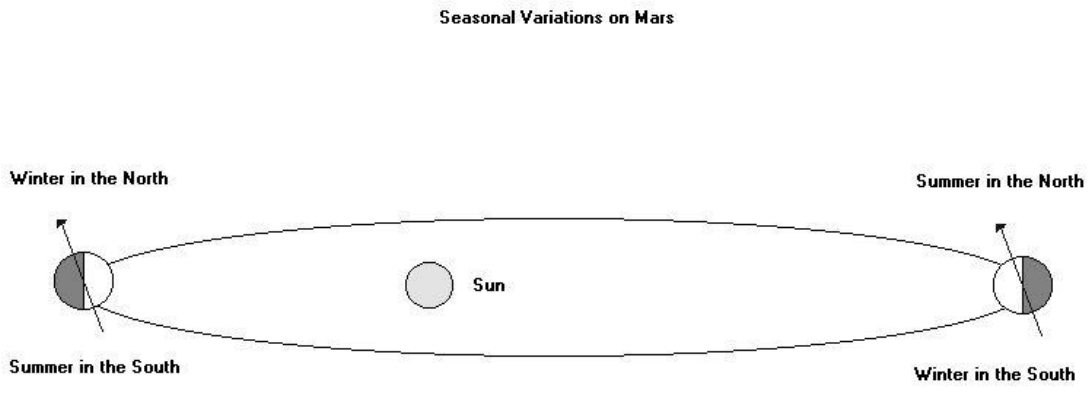
Visual Appearance:
Mars appears quite red to the unaided eye. Through a telescope Mars is red and shows some dark patches and white polar caps.

The best time to observe Mars is at opposition when it is closest to the Earth. At this time Mars shows a full phase.

At quadrature (angle between Mars, Earth and Sun is 90^{o}) Mars shows a gibbous phase.

Seasons:
Two factors are responsible for seasons on Mars:

1. Axial tilt.
2. Eccentricity of its orbit.



In the northern hemisphere the seasons are moderated by the varying distance from the Sun.

Summer: Mars farthest from Sun.
Winter: Mars closest to Sun.

However, in the southern hemisphere the seasons are at extremes, which leads to seasonal dust storms.

Summer: Mars closest to Sun.
Winter: Mars farthest from Sun

Atmosphere

Composition: carbon dioxide - 95.3%
nitrogen - 2.7%
argon - 1.6%
water vapor - 0.03% (variable)

Pressure: 1/150 the pressure of the Earth's atmosphere at sea level.

Evolution:
Primary atmosphere: similar to Venus and Earth

Secondary atmosphere: At first, it was probably thick like the Earth's atmosphere with a large amount of water vapor as indicated by dry riverbeds. Presence of liquid water depleted CO_2 resulting in a runaway reverse greenhouse effect.

Cooling resulted in H_2O freezing out of atmosphere thus accelerating the cooling.

Atmospheric pressure decreased as a result of the Sun's UV radiation splitting molecules into their lighter constituents that escaped the planets weak gravity.

Martian Surface

Northern Hemisphere:
Rolling volcanic planes (like lunar maria) with much fewer craters than southern hemisphere (about 3 billion years old).

Southern Hemisphere:
Heavily cratered highlands (about 4 billion years old).

Tharsis Bulge:
Largest geological feature. Very young (very few craters). 10 km higher than surrounding surface.

Volcanism:
Large shield volcanoes located on the Tharsis Bulge. Most likely extinct.

Largest volcano - Olympus Mons. 700 km in diameter and rises 25 km above surrounding planes.

Concept Test

Volcanoes on Mars have become much larger than on Earth mostly because Mars lacks
a) a thick atmosphere.
b) flowing water.
c) plate tectonics.
d) a large moon.

Cratering:
Most craters smaller than 5 km have been erased by air born dust. Ejecta blankets (fluidized ejecta) give evidence of permafrost on Mars.

Martian Grand Canyon:
Valles Marineris is a tectonic fracture that extends for about 4000 km and is about 120 km across.

Running Water:
1. runoff channels - dry riverbeds.
2. outflow channels - results of past flooding.

Polar Caps:
Seasonal Caps - composed of dry ice (CO_2) that evaporates in summer.

Northern Residual Cap - composed mostly of water ice.

Southern Residual Cap - composed mostly of water ice.

Surface Composition: Soil is rich in iron oxide, which indicates that Mars is not highly differentiated.

Internal Structure

No magnetic field has been detected leading to the conclusion that the core must be solid or nonmetallic.

Crust was not molten long enough to allow heavy elements to sink to the center.

Lack of a large nickel-iron core is indicated by the low overall density of 3.9 grams/cm^3.

Mars Pathfinder results indicate a larger core than previously thought.

Moons

Two moons: both are probably captured asteroids and keep one face towards Mars.

Phobos - 28 km long and 20 km wide. Appears to rise in west and set in east due to its 7 hr period of revolution.

Deimos - 16 km by 10 km.

Search for Life:
Viking landers carried out experiments to determine if life was present.

Results seemed to indicate life was present but they all could be explained by inorganic chemical reactions.