Guiding Questions

1. Is the Moon completely covered with craters?
2. Has there been any exploration of the Moon since the Apollo program in the 1970s?
3. Does the Moon’s interior have a similar structure to the interior of the Earth?
4. How do Moon rocks compare to rocks found on the Earth?
5. How did the Moon form?
<table>
<thead>
<tr>
<th><strong>Moon Data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance from Earth</strong>&lt;br&gt;(center to center):</td>
</tr>
<tr>
<td><strong>Eccentricity of orbit:</strong></td>
</tr>
<tr>
<td><strong>Average orbital speed:</strong></td>
</tr>
<tr>
<td><strong>Sidereal period (relative to fixed stars):</strong></td>
</tr>
<tr>
<td><strong>Synodic period (new moon to new moon):</strong></td>
</tr>
<tr>
<td><strong>Inclination of lunar equator to orbit:</strong></td>
</tr>
<tr>
<td><strong>Inclination of orbit to ecliptic:</strong></td>
</tr>
<tr>
<td><strong>Diameter (equatorial):</strong></td>
</tr>
<tr>
<td><strong>Mass:</strong></td>
</tr>
<tr>
<td><strong>Average density:</strong></td>
</tr>
<tr>
<td><strong>Escape speed:</strong></td>
</tr>
<tr>
<td><strong>Surface gravity (Earth = 1):</strong></td>
</tr>
<tr>
<td><strong>Albedo:</strong></td>
</tr>
<tr>
<td><strong>Average surface temperatures:</strong>&lt;br&gt;<strong>Day:</strong> 130°C = 266°F = 403 K&lt;br&gt;<strong>Night:</strong> −180°C = −292°F = 93 K</td>
</tr>
<tr>
<td><strong>Atmosphere:</strong></td>
</tr>
</tbody>
</table>
The Moon’s Orbit

- The Moon and Earth both orbit around a point between their centers called the center of mass of the Earth-Moon system.

- The center of mass then follows an elliptical orbit around the Sun.
An Everyday Example of Center of Mass Motion

Motion of the Earth-Moon Center of Mass

Center of mass of the Earth-Moon system

Earth

Moon

Center of mass moves in an elliptical orbit around the sun
## Moon

<table>
<thead>
<tr>
<th>Major Regions</th>
<th>Appearance</th>
<th>Process Formed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highlands</td>
<td>Bright</td>
<td>meteor impact</td>
</tr>
<tr>
<td><strong>Age? old</strong></td>
<td>Heavily cratered</td>
<td></td>
</tr>
<tr>
<td>Mare Basins</td>
<td>Dark</td>
<td>asteroid impact</td>
</tr>
<tr>
<td><strong>Age? young</strong></td>
<td></td>
<td>lava flows</td>
</tr>
</tbody>
</table>
1. Meteor Bombardment

P.E.  \rightarrow  K.E.

K.E.  \rightarrow  heat - melts rock

Source: Dr. James Regas Cal State Chico
2. Radioactive Heating by

U - uranium, K - potassium, & Th - thorium

Heat melts interior

Source: Dr. James Regas Cal State Chico
 Rays - thin dusting of lunar material

Source: Dr. James Regas Cal State Chico
Principle of Superposition and Cross-cutting
A crater with rays forms.

Mare Basin

Source: Dr. James Regas Cal State Chico
Principle of Superposition and Cross-cutting:
Oldest on bottom. Youngest on top.

Source: Dr. James Regas Cal State Chico
Cratering History of Moon

Crater density = [number of craters]/area

Crater density = 5 craters/km²

Source: Dr. James Regas Cal State Chico
Lunar Features

Rilles - valleys

Loading of Mare Basins by lava causes tension.

Source: Dr. James Regas Cal State Chico
Lava flows in.

What does crater density become?

Lava Flow -->

1 km

1 km

Source: Dr. James Regas Cal State Chico
Period of Catastrophic Bombardment any life that arose on Earth destroyed.
The Moon’s airless, dry surface is covered with plains and craters

- The Earth-facing side of the Moon displays light-colored, heavily cratered highlands and dark-colored, smooth-surfaced maria
- The Moon’s far side has almost no maria
Another View of the Moon

- Maria
- Craters
- Lunar highlands
• Virtually all lunar craters were caused by space debris striking the surface

• There is no evidence of plate tectonic activity on the Moon
The maria formed after the surrounding light-colored terrain, so they have not been exposed to meteoritic bombardment for as long and have fewer craters.
Human exploration of the lunar surface

(a) View from Ranger 9

(b) Same view from Earth

50 km
Much of our knowledge about the Moon has come from human exploration in the 1960s and early 1970s and from more recent observations by unmanned spacecraft.
The Lunar Surface Provides Clues about its Structure and Formation

Near side  Far side

Iron content (percentage by weight)
• Meteoroid impacts have been the only significant erosion agent on the Moon

• The Moon’s regolith, or surface layer of powdered and fractured rock, was formed by meteoritic action
All of the lunar rock samples are igneous rocks formed largely of minerals found in terrestrial rocks.

- The lunar rocks contain no water.
- They differ from terrestrial rocks in being relatively enriched in the refractory elements and depleted in the volatile elements.
Lunar rocks reveal a geologic history quite unlike that of Earth

- The anorthositic crust exposed in the highlands was formed between 4.0 and 4.3 billion years ago.
- The mare basalts solidified between 3.1 and 3.8 billion years ago.
- The Moon’s surface has undergone very little change over the past 3 billion years.
The Moon has no global magnetic field but has a small core beneath a thick mantle.
The Formation of the Moon

• The collisional-ejection theory
  – Successfully explains most properties of the Moon
  – Hypothesizes that the proto-Earth was struck by a Mars-sized protoplanet and that debris from this collision coalesced to form the Moon

• The Moon was molten in its early stages, and the anorthositic crust solidified from low-density magma that floated to the lunar surface

• The mare basins were created later by the impact of planetesimals and filled with lava from the lunar interior

• Other alternate theories that fail in areas
  – Co-creation (sister), fission, capture
**Origin of the Moon**

1. Fission Theory - Moon split off from spinning Earth.

Prediction: chemical composition of Moon, same as Earth or different?

Do Apollo results favor this theory?

Source: Dr. James Regas Cal State Chico
2. **Accretion Theory** - Moon formed from material left over from the Earth.

Dust cloud that forms Earth

![Diagram showing Earth and Moon with a dust cloud forming Earth.]

Prediction: chemical composition of Moon, same as Earth or different?

Do Apollo results favor this theory?

Source: Dr. James Regas Cal State Chico
3. Capture Theory

Moon formed elsewhere in solar system

Earth

Later Moon captured by Earth.

sun

Prediction: chemical composition of Moon, same as Earth or different?

Do Apollo results favor this theory?

Is capture probable or improbable? 1 click

Source: Dr. James Regas Cal State Chico
4. Large impact theory.

1. Impact of large Mars-sized object ejects huge amount of material which forms Moon.

2. Impact heated materials & drove off volatiles like water.

3. Material later condensed to form the Moon.

Prediction: chemical composition of Moon, same as Earth or different? _________

Do Apollo results favor this theory? _______

Most widely accepted theory.

Source: Dr. James Regas Cal State Chico
During middle to late stages of Earth’s accretion, about 4.5 billion years ago, a Mars-sized body impacted the Earth...

And the giant impact quickly propelled a shower of debris from both the impactor and Earth into space.

The impact sped up Earth’s rotation and tilted Earth’s orbital plane 23°.

Earth re-formed as a largely molten body...

...and the Moon aggregated from the debris.

Ancient moon rocks brought back by the Apollo astronauts support this impact hypothesis.
Tidal interactions between the Earth and Moon are slowing the Earth’s rotation and causing the Moon to move away from the Earth.
1. The Moon’s tidal forces elongate Earth’s oceans along an Earth-Moon line.

2. Friction between the spinning Earth and its oceans drags the tidal bulge about $10^\circ$ ahead of alignment with the moon.

3. Friction between Earth and its oceans also makes the Earth rotate more slowly, increasing the length of the day.

4. The tidal bulge on the side nearest the Moon exerts a small forward force on the Moon, making it spiral slowly away from Earth.
The Moon—Site of Future Industry? Not!
Lunar Colonies: Why would it be difficult to live on the Moon?

1. No atmosphere

Large temperature variation:

Daytime: \( T = 100^\circ C \) boiling pt. of \( H_2O \)

Night time: \( T = -173^\circ C \)

Cosmic rays hit surface. Must live 11 ft below ground.

2. No water (maybe)


Source: Dr. James Regas Cal State Chico
Why it is better to live on Moon?

1. No Moonquakes

2. Gravity weaker - easier to build large structures. (Although need to protect from meteors.)


4. No radio or TV stations. Better for radio astronomers.

Source: Dr. James Regas Cal State Chico
Lunar Resources

1. Source of Al, Fe, Si, Ti, Mg & O.

Takes 22 x less energy to lift off of Moon.

Rocket carrying O_2

2. Lunar soil can be used for shielding space colony.

3. No atmosphere better for telescopes.
Key Words

- anorthosite
- capture theory
- center of mass
- co-creation theory
- collisional ejection theory
- crater
- far side (of the Moon)
- fission theory
- impact breccia
- impact crater
- libration
- lunar highlands
- mare (*plural* maria)
- mare basalt
- moonquake
- refractory element
- regolith
- synchronous rotation
- terminator
- terrae
- volatile element