Planetary Atmospheres: Earth and the Other Terrestrial Worlds
What is an atmosphere?

- An atmosphere is a layer of gas that surrounds a world.
Earth's Atmosphere

• About 10 kilometers thick

• Consists mostly of molecular nitrogen ($N_2$) and oxygen ($O_2$).
Where does an atmosphere end?

- There is no clear upper boundary.
- Most of Earth's gas is less than 10 kilometers from surface, but a small fraction extends to more than 100 kilometers.
- Altitudes more than 100 kilometers are considered "space."
Effects of Atmospheres

• They create pressure that determines whether liquid water can exist on surface.
• They absorb and scatter light.
• They create wind, weather, and climate.
• They can make planetary surfaces warmer through the greenhouse effect.
Earth’s atmosphere is opaque to most harmful radiation from space — X-rays and most UV
Greenhouse Effect

- Certain gases in the Earth’s atmosphere act as a thermal blanket, insulating the Earth from the cold of space.
- These gases are called greenhouse gases – primarily include \( \text{H}_2\text{O} \) (water vapor), \( \text{CO}_2 \) (carbon dioxide), and \( \text{CH}_4 \) (methane).
Venus’ Atmosphere

• Much denser than Earth’s
  – surface pressure on Venus is 90 times higher than on Earth
  – equivalent to diving 1 km below the surface of the ocean on Earth
Venus’ Atmosphere

• Surface of Venus is covered by a perpetual layer of clouds
  – cover the entire surface
  – opaque
    • can’t “see” the surface of Venus
    • by same token, couldn’t see the Sun or stars from the surface of Venus
  – have learned about the surface through
    • radar images
    • spacecraft landings
### Atmosphere Comparison

- **Venus**
  - clouds are made of droplets of concentrated sulfuric acid
    - may rain acid
  - CO$_2$ : 96%
  - N$_2$ : 3%

- **Earth**
  - clouds are made of water vapor
    - rains water
  - N$_2$ : 78%
  - O$_2$ : 21%
Greenhouse Effect

- High CO$_2$ content in Venus’ atmosphere has led to extreme greenhouse effect
  - Raises temperature of Venus 400° C (720 ° F) over what it would be without a greenhouse gases
  - This in spite of the fact that the clouds in Venus’ atmosphere reflect 59% of sunlight back into space (albedo=0.59)

- Leading theory is that Venus started out much more like Earth, but underwent runaway greenhouse effect
Runaway Greenhouse Effect

- Greenhouse gases increase because:
  - water evaporates out of oceans
  - CO$_2$ bakes out of rocks

Some scientists fear something similar could happen on Earth
Runaway Greenhouse Effect

(a) Earth: H$_2$O, CO$_2$, and SO$_2$ are recycled

1. H$_2$O, CO$_2$, and SO$_2$ are outgassed from volcanoes.
2. H$_2$O falls as rain, CO$_2$ and SO$_2$ dissolve in the oceans.
3. CO$_2$, SO$_2$, and some H$_2$O are incorporated into sedimentary rocks.
4. The sedimentary rocks are eventually subducted to great depths, where heat liberates the gases.
5. The liberated H$_2$O, CO$_2$, and SO$_2$ rise upward by volcanic action.

(b) Venus: H$_2$O, CO$_2$, and SO$_2$ are NOT recycled

1. H$_2$O, CO$_2$, and SO$_2$ are outgassed from volcanoes.
2. With no oceans to dissolve in, CO$_2$ becomes part of the atmosphere.
3. Some H$_2$O and SO$_2$ combine to form H$_2$SO$_4$ (sulfuric acid) in Venus's clouds.
4. Remaining H$_2$O molecules break apart due to ultraviolet radiation from the Sun.
5. Remaining SO$_2$ molecules are locked up in minerals.
# Atmosphere Comparison

<table>
<thead>
<tr>
<th>Earth</th>
<th>Venus</th>
<th>Mars</th>
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</thead>
<tbody>
<tr>
<td>- Moderate temperature</td>
<td>- Runaway greenhouse</td>
<td>- Runaway icehouse</td>
</tr>
<tr>
<td>- Moderate pressure (1 atm)</td>
<td>- Very high pressure (90 atm)</td>
<td>- Low pressure (0.01 atm)</td>
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<td>- N$_2$ : 3.5%</td>
<td>- N$_2$ : 3%</td>
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<tr>
<td>- H$_2$O: 1%</td>
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Even though Mars’ atmosphere is still mostly CO$_2$, there isn’t enough of it to raise the temperature significantly.
Runaway Icehouse Effect

• Greenhouse gases decrease because:
  – rain washed CO$_2$ out of atmosphere
  – CO$_2$ locked into carbonate rocks
  – little geologic activity on Mars meant CO$_2$ remained trapped

Decreased Temperature

Decreased Greenhouse Gases
Runaway Icehouse Effect

1. Outgassing added water and carbon dioxide to the early atmosphere.
2. Ultraviolet light from the Sun broke some water molecules apart; hydrogen atoms escaped into space.
3. Other water molecules rained downward, forming oceans.
4. When plant life appeared, it released oxygen through photosynthesis.
5. Carbon dioxide goes into carbonate rocks; since plate tectonics is active on Earth, carbon dioxide is eventually recycled into the atmosphere through outgassing.

(a) Earth

1. Ultraviolet light from the sun broke some water molecules apart; due to the weaker gravity, both hydrogen and oxygen escape.
2. The weaker gravity also allowed carbon and nitrogen atoms to escape.

(b) Mars

3. The colder temperatures caused the remaining water to freeze beneath the surface.
4. Carbon dioxide went into carbonate rocks and the regolith; since plate tectonics is not active on Mars, carbon dioxide is not recycled into the atmosphere.