Chapter 10
Planetary Atmospheres
Earth and the Other Terrestrial Worlds

10.1 Atmospheric Basics

Our goals for learning:

- What is an atmosphere?
- How does the greenhouse effect warm a planet?
- Why do atmospheric properties vary with altitude?

Earth's Atmosphere

- About 10 km thick
- Consists mostly of molecular nitrogen (N_2) and oxygen (O_2)

Atmospheric Pressure

Gas pressure depends on both density and temperature.

Adding air molecules increases the pressure in a balloon.

Heating the air also increases the pressure.

Atmospheric Pressure

- Pressure and density decrease with altitude because the weight of overlying layers is less
- Earth's pressure at sea level is
  - 1.03 kg per sq. meter
  - 14.7 lbs per sq. inch
  - 1 bar

Where does an atmosphere end?

- There is no clear upper boundary
- Most of Earth's gas is < 10 km from surface, but a small fraction extends to >100 km
- Altitudes >60 km are considered "space"

Effects of Atmospheres

- Create pressure that determines whether liquid water can exist on surface
- Absorb and scatter light
- Create wind, weather, and climate
- Interact with solar wind to create a magnetosphere
- Can make planetary surfaces warmer through greenhouse effect

Greenhouse Effect

- Visible light passes through atmosphere and warms planet's surface
- Atmosphere absorbs infrared light from surface, trapping heat

Interactive Figure

"No Greenhouse" Temperatures

- Venus would be 510°C colder without greenhouse effect
- Earth would be 31°C colder (below freezing on average)

Earth's Atmospheric Structure

- **Troposphere:** lowest layer of Earth's atmosphere
- Temperature drops with altitude
- Warmed by infrared light from surface and convection

Earth's Atmospheric Structure

- **Stratosphere:** Layer above the troposphere
- Temperature rises with altitude in lower part, drops with altitude in upper part
- Warmed by absorption of ultraviolet sunlight

Earth's Atmospheric Structure

- **Thermosphere:** Layer at about 100 km altitude
- Temperature rises with altitude
- X rays and ultraviolet light from the Sun heat and ionize gases

Earth's Atmospheric Structure

- **Exosphere:** Highest layer in which atmosphere gradually fades into space
- Temperature rises with altitude; atoms can escape into space
- Warmed by X rays and UV light

Why the sky is blue

- Atmosphere scatters blue light from Sun, making it appear to come from different directions
- Sunsets are red because red light scatters less

Atmospheres of Other Planets

- Earth is only planet with a stratosphere because of UV-absorbing ozone molecules (O_3).
- Those same molecules protect us from Sun's UV light.

No greenhouse temperatures

Solar Brightening

- Sun very gradually grows brighter with time, increasing the amount of sunlight warming planets

Changes in Axis Tilt

- Greater tilt makes more extreme seasons, while smaller tilt keeps polar regions colder

Changes in Axis Tilt

- Small gravitational tugs from other bodies in solar system cause Earth's axis tilt to vary between 22° and 25°

Changes in Reflectivity

- Higher reflectivity tends to cool a planet, while lower reflectivity leads to warming

Changes in Greenhouse Gases

- Increase in greenhouse gases leads to warming, while a decrease leads to cooling

What have we learned?

- What creates wind and weather?
  - Atmospheric heating and Coriolis effect
- What factors can cause long-term climate change?
  - Brightening of Sun
  - Changes in axis tilt
  - Changes in reflectivity
  - Changes in greenhouse gases

What have we learned?

- How does a planet gain or lose atmospheric gases?
  - Gains: Outgassing, evaporation/sublimation, and impacts by particles and photons
  - Losses: Condensation, chemical reactions, blasting by large impacts, sweeping by solar winds, and thermal escape

10.3 Atmospheres of Moon and Mercury

Our goals for learning:

- Do the Moon and Mercury have any atmosphere at all?

Exospheres of Moon and Mercury

Moon Mercury

- Sensitive measurements show Moon and Mercury have extremely thin atmospheres
- Gas comes from impacts that eject surface atoms

What have we learned?

- Do the Moon and Mercury have any atmosphere at all?
  - Moon and Mercury have very thin atmospheres made up of particles ejected from surface

10.4 The Atmospheric History of Mars

Our goals for learning:

- What is Mars like today?
- Why did Mars change?

Polar Ice Caps of Mars

Late winter Midspring Early summer

- Carbon dioxide ice of polar cap sublimates as summer approaches and condenses at opposite pole

Polar Ice Caps of Mars

- Residual ice of polar cap during summer is primarily water ice

Dust Storms on Mars

- Seasonal winds can drive dust storms on Mars
- Dust in the atmosphere absorbs blue light, sometimes making the sky look brownish-pink

Changing Axis Tilt

- Calculations suggest Mars's axis tilt ranges from 0° to 60° over long time periods
- Such extreme variations cause dramatic climate changes
- These climate changes can produce alternating layers of ice and dust

Climate Change on Mars

- Mars has not had widespread surface water for 3 billion years
- Greenhouse effect probably kept surface warmer before that
- Somehow Mars lost most of its atmosphere

Climate Change on Mars

- Magnetic field may have preserved early Martian atmosphere
- Solar wind may have stripped atmosphere after field decreased because of interior cooling

What have we learned?

- What is Mars like today?
  - Mars is cold, dry, and frozen
  - Strong seasonal changes cause CO_2 to move from pole to pole, leading to dust storms
- Why did Mars change?
  - Its atmosphere must have once been much thicker for its greenhouse effect to allow liquid water on the surface
  - Somehow Mars lost most of its atmosphere, perhaps because of declining magnetic field

10.5 The Atmospheric History of Venus

Our goals for learning:

- What is Venus like today?
- How did Venus get so hot?

Atmosphere of Venus

- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times Earth's
- Slow rotation produces very weak Coriolis effect and little weather

Greenhouse Effect on Venus

- Thick carbon dioxide atmosphere produces an extremely strong greenhouse effect
- Earth escapes this fate because most of its carbon and water is in rocks and oceans

Atmosphere of Venus

- Reflective clouds contain droplets of sulphuric acid
- Upper atmosphere has fast winds that remain unexplained

Runaway Greenhouse Effect

- Runaway greenhouse effect would account for why Venus has so little water

What have we learned?

- What is Venus like today?
  - Venus has an extremely thick CO_2 atmosphere
  - Slow rotation means little weather
- How did Venus get so hot?
  - Runaway greenhouse effect made Venus too hot for liquid oceans
  - All carbon dioxide remains in atmosphere, leading to a huge greenhouse effect