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?**

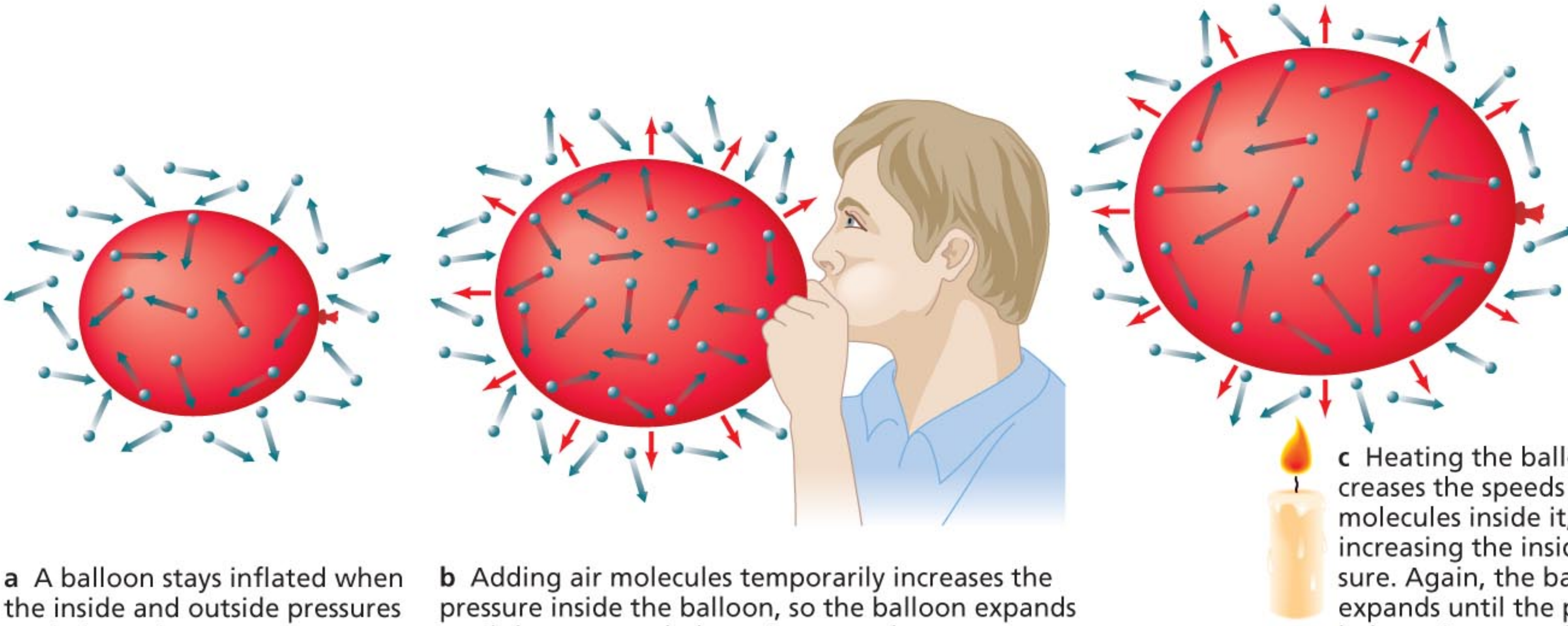
What is an atmosphere?

- 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).

Atmospheric Pressure

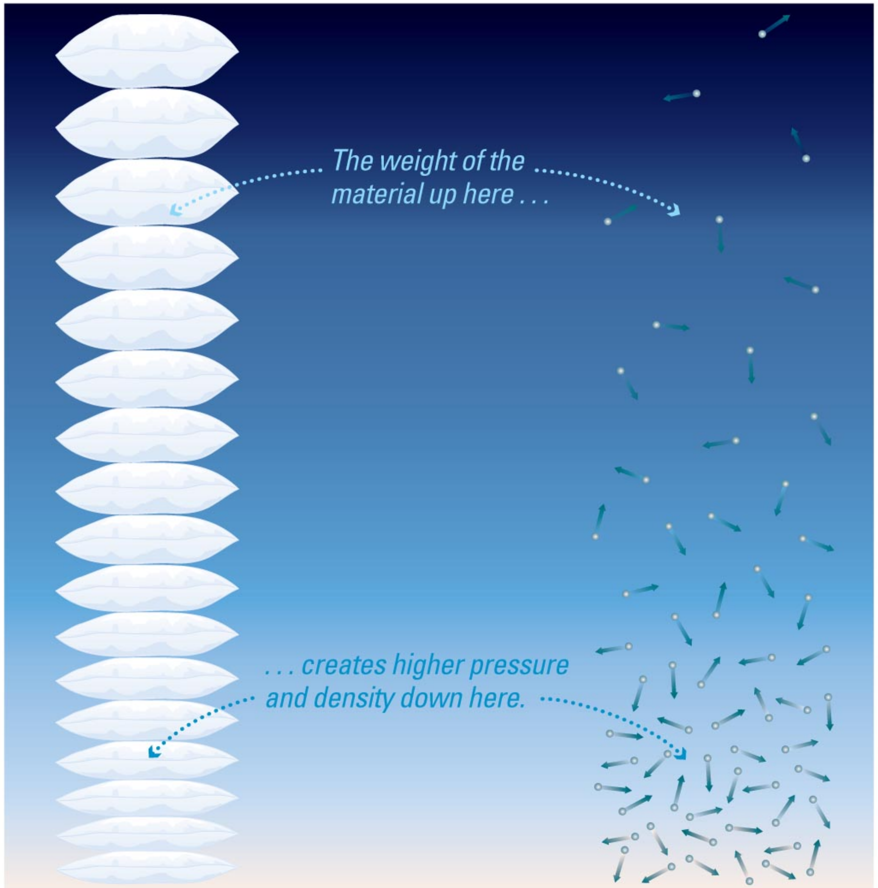


a A balloon stays inflated when the inside and outside pressures are balanced.

b Adding air molecules temporarily increases the pressure inside the balloon, so the balloon expands until the pressure balance is restored.

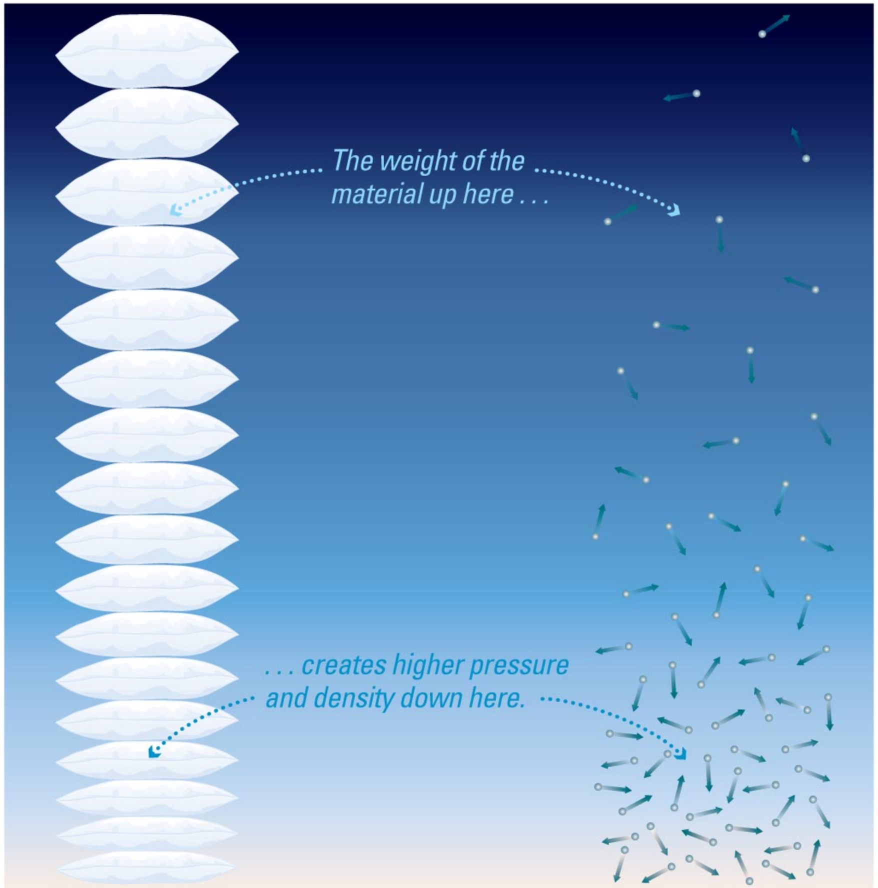
c Heating the balloon increases the speeds of air molecules inside it, thereby increasing the inside pressure. Again, the balloon expands until the pressure balance is restored.

Atmospheric Pressure



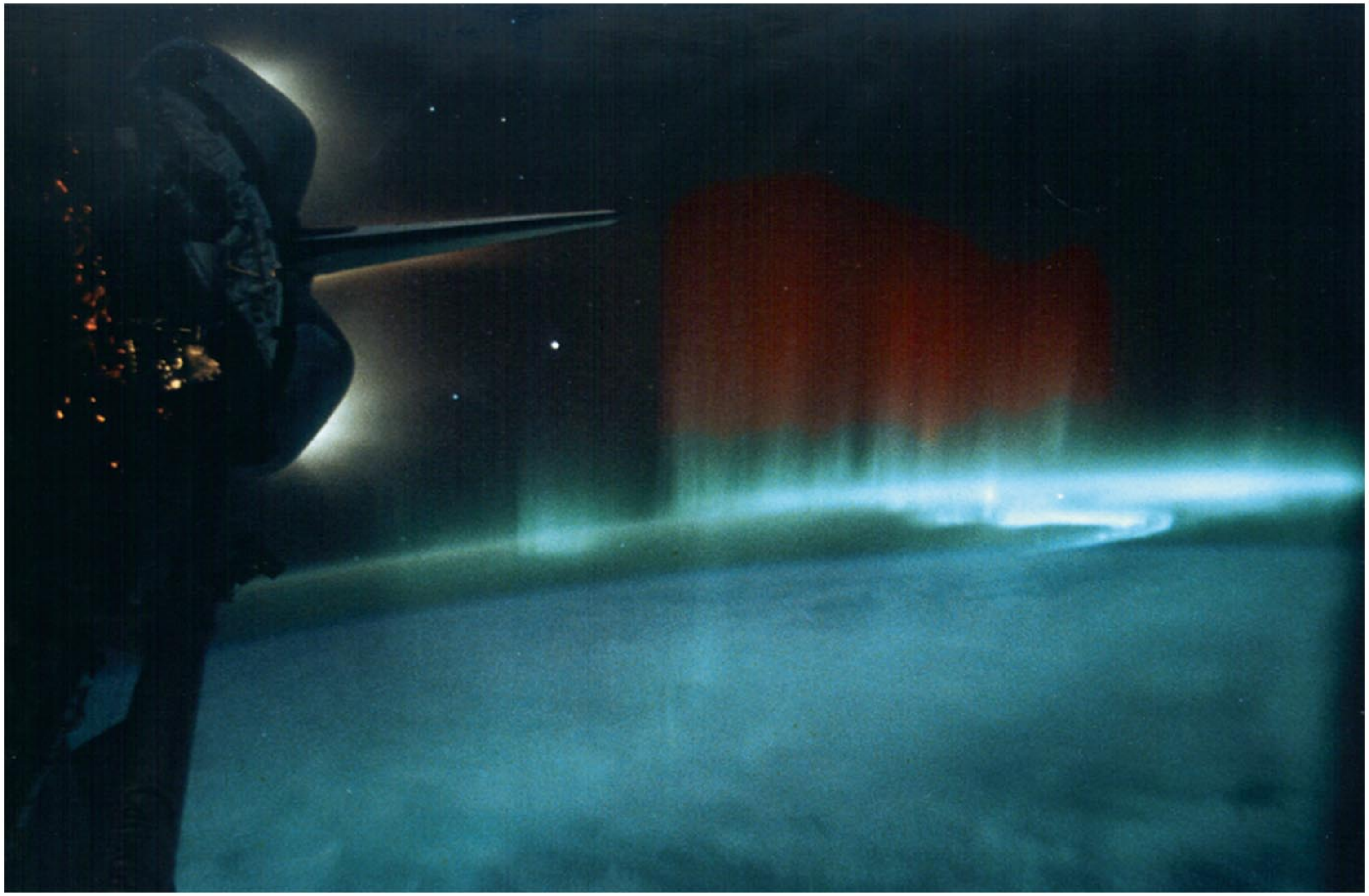
- Pressure and density decrease with altitude because the weight of overlying layers is less.
- Earth's pressure at sea level is:
  - 1.03 kg per sq. meter
  - 14.7 lb per sq. inch
  - 1 “bar”
  - 1 “atmosphere”

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."

Where does an atmosphere end?

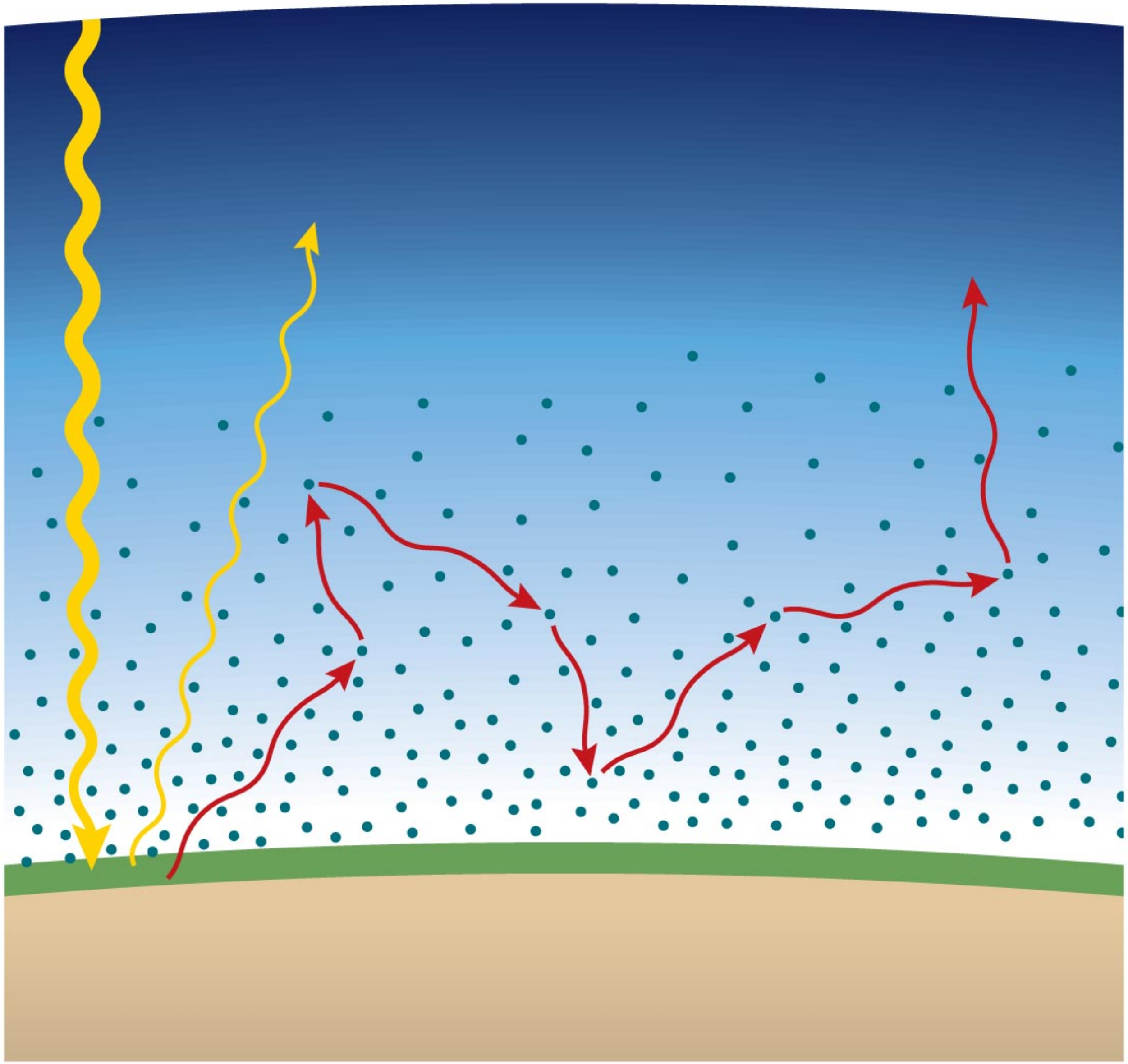


- Small amounts of gas are present even above 300 kilometers.

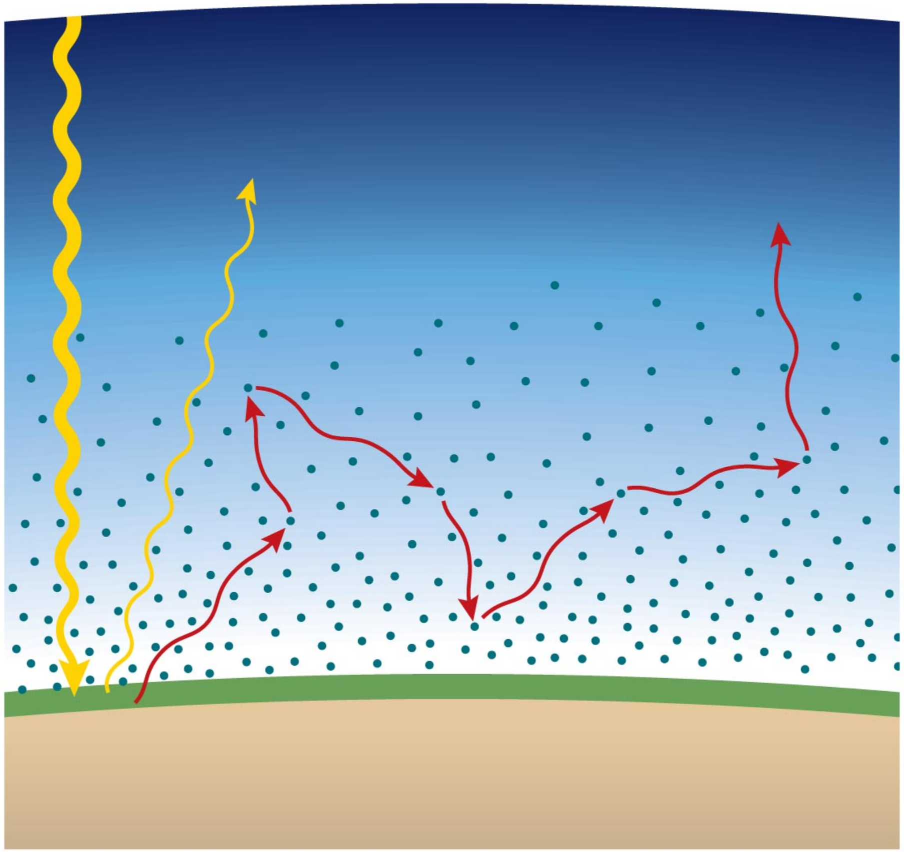
Effects of Atmospheres

- They create pressure that determines whether liquid water can exist on surface.
- They absorb and scatter light.
- They create wind, weather, and climate.
- They interact with the solar wind to create a magnetosphere.
- They can make planetary surfaces warmer through the greenhouse effect.

How does the greenhouse effect warm a planet?

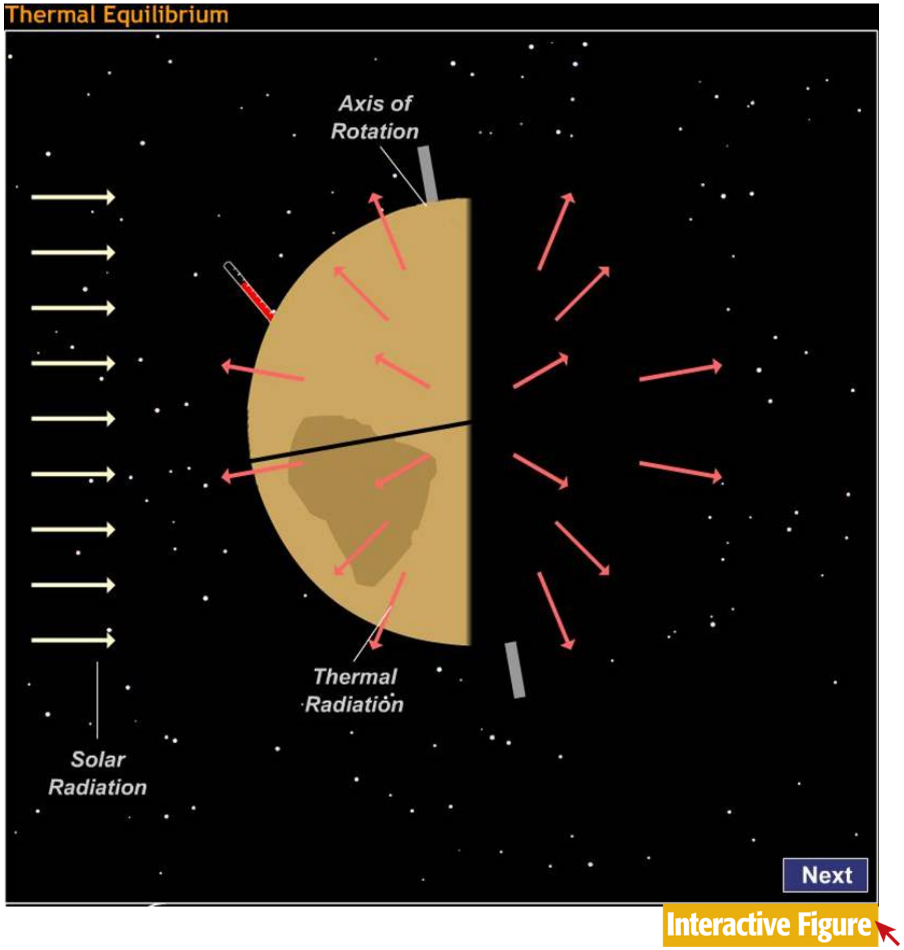


Greenhouse Effect



- Visible light passes through the atmosphere and warms a planet's surface.
- The atmosphere absorbs infrared light from the surface, trapping heat.
- Carbon dioxide (CO_2) and water vapor (H_2O) are strongest absorbers.

Planetary Temperature

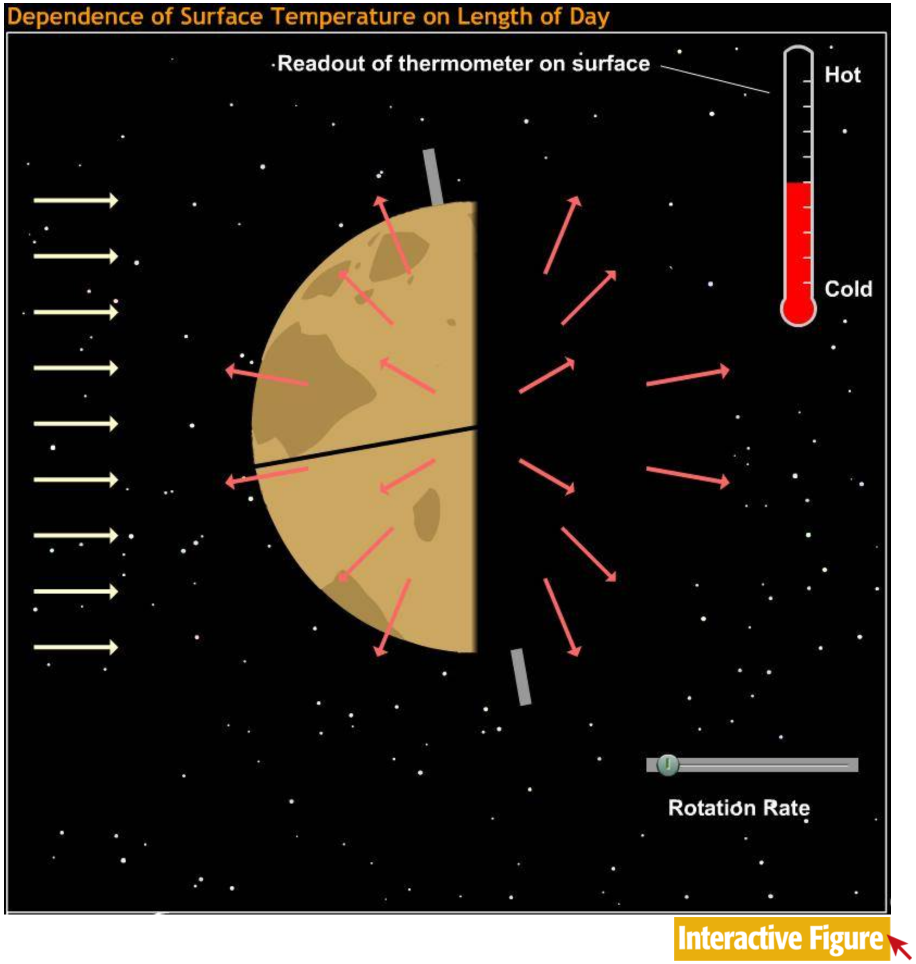


- A planet's surface temperature is determined by the balance between energy from sunlight it absorbs and energy of outgoing thermal radiation.

Temperature and Distance

- A planet's distance from the Sun determines the total amount of incoming sunlight.

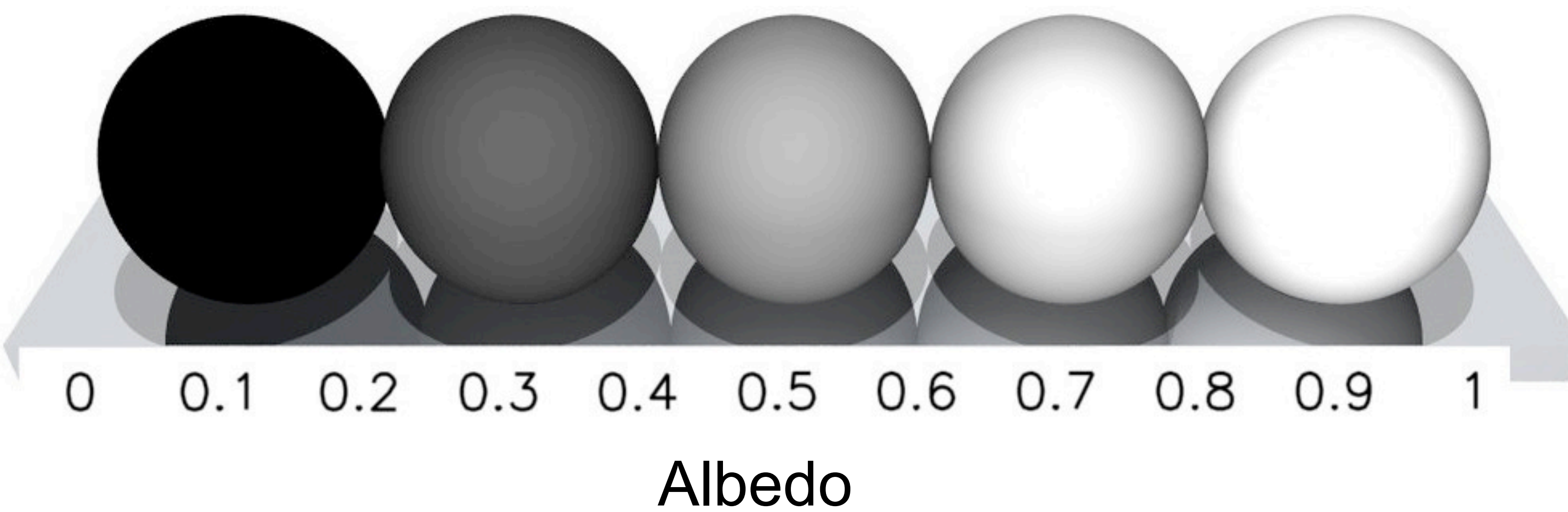
Temperature and Rotation



- A planet's rotation rate affects the temperature differences between day and night.

Temperature and Reflectivity

- A planet's reflectivity (or ***albedo***) is the fraction of incoming sunlight it reflects.
- Planets with low albedo absorb more sunlight, leading to hotter temperatures.



"No Greenhouse" Temperatures

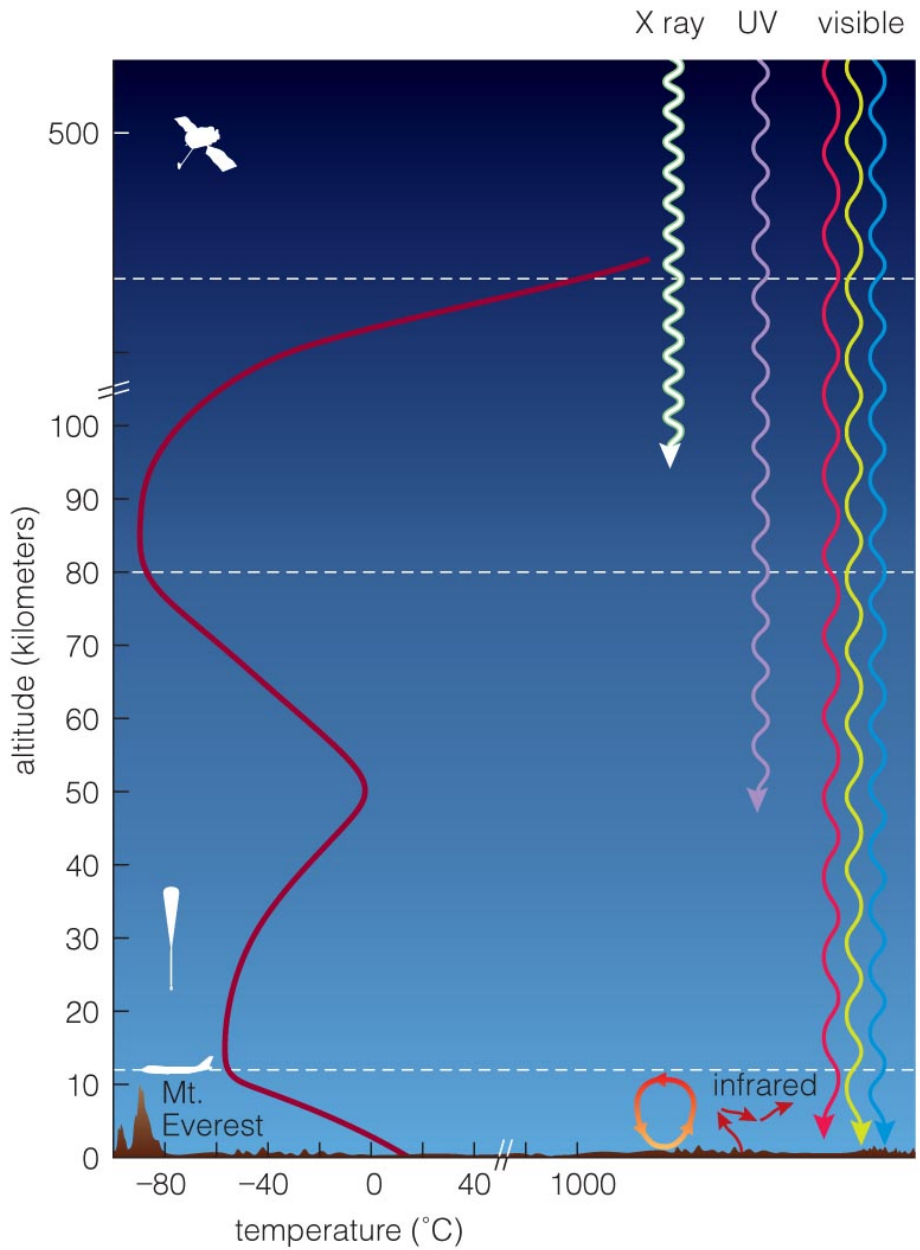
TABLE 10.2 The Greenhouse Effect on the Terrestrial Worlds

World	Average Distance from Sun (AU)	Reflectivity	"No Greenhouse" Average Surface Temperature*	Actual Average Surface Temperature	Greenhouse Warming (actual temperature minus "no greenhouse" temperature)
Mercury	0.387	12%	163°C	day: 425°C night: –175°C	—
Venus	0.723	75%	–40°C	470°C	510°C
Earth	1.00	29%	–16°C	15°C	31°C
Moon	1.00	12%	–2°C	day: 125°C night: –175°C	—
Mars	1.524	16%	–56°C	–50°C	6°C

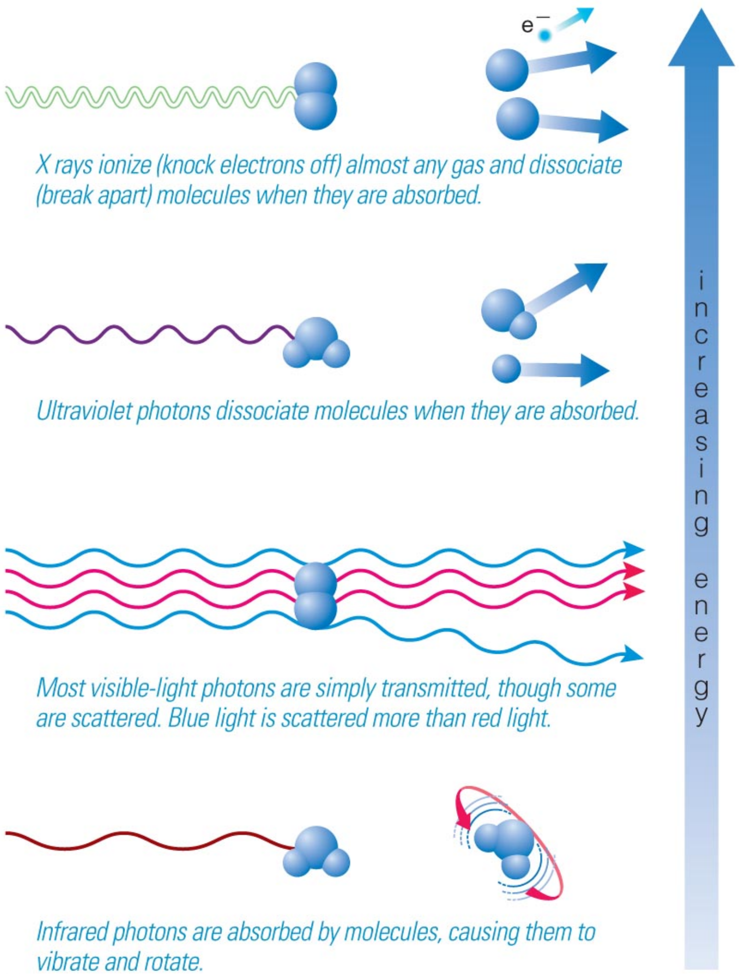
*The "no greenhouse" temperature is calculated by assuming no change to the atmosphere other than lack of greenhouse warming. For example, Venus has a lower "no greenhouse" temperature than Earth even though it is closer to the Sun, because the high reflectivity of its bright clouds means that it absorbs less sunlight than Earth.

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

Why do atmospheric properties vary with altitude?

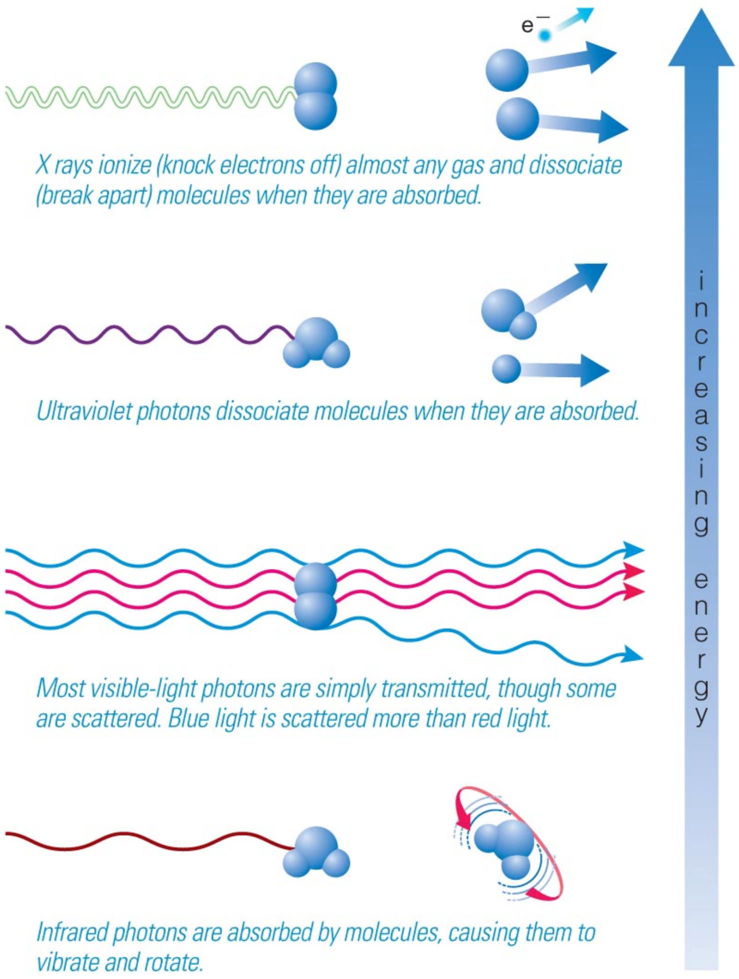


Light's Effects on Atmosphere



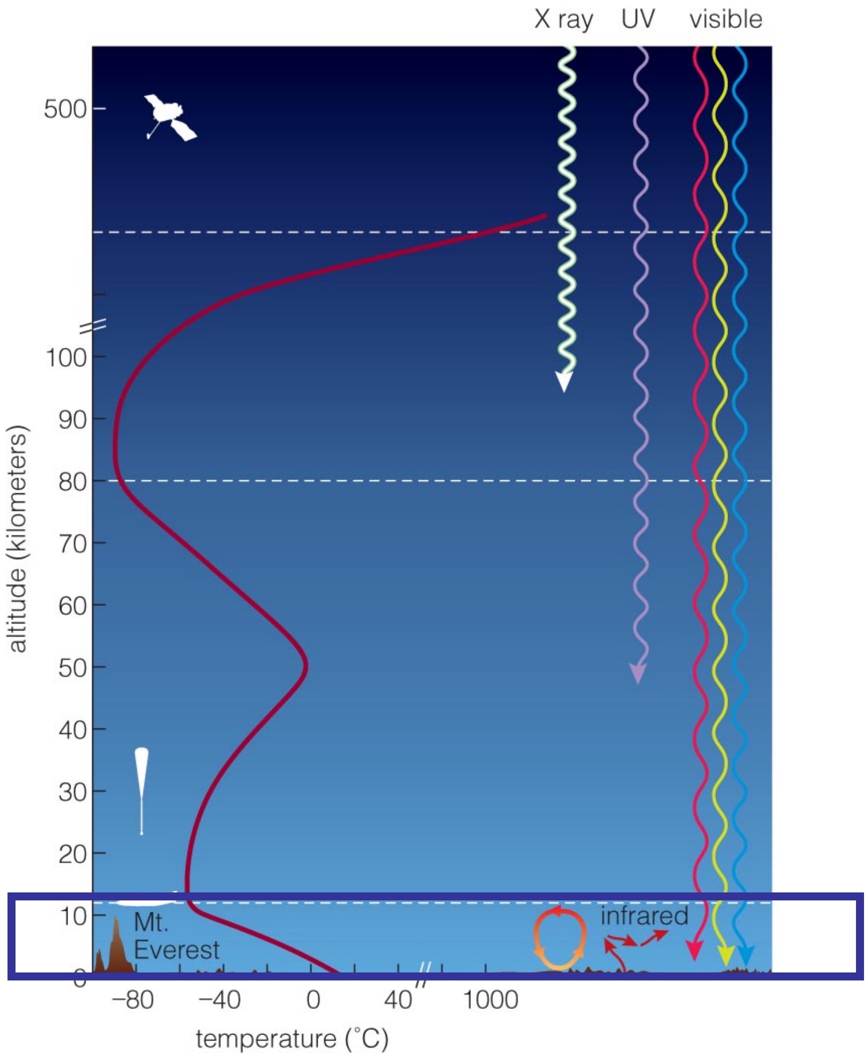
- **Ionization:** removal of an electron
- **Dissociation:** destruction of a molecule
- **Scattering:** change in photon's direction
- **Absorption:** photon's energy is absorbed.

Light's Effects on Atmosphere



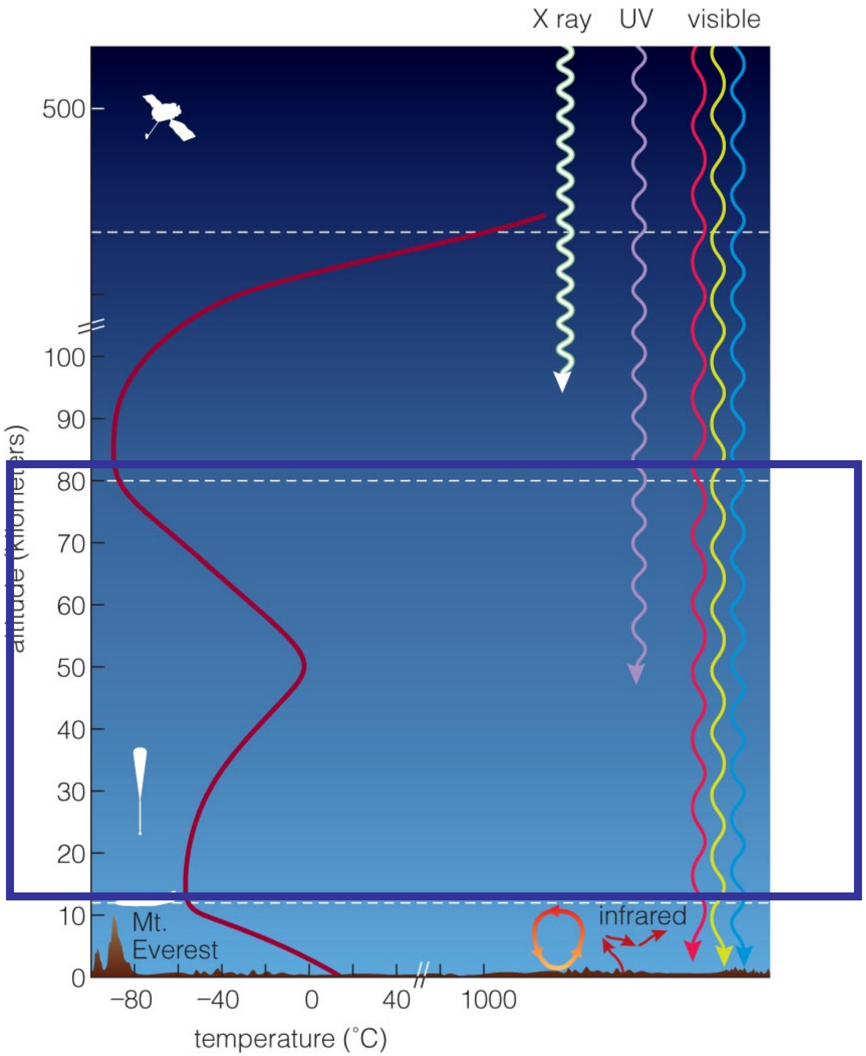
- X rays and UV light can ionize and dissociate molecules.
- Molecules tend to scatter blue light more than red.
- Molecules can absorb infrared light.

Earth's Atmospheric Structure



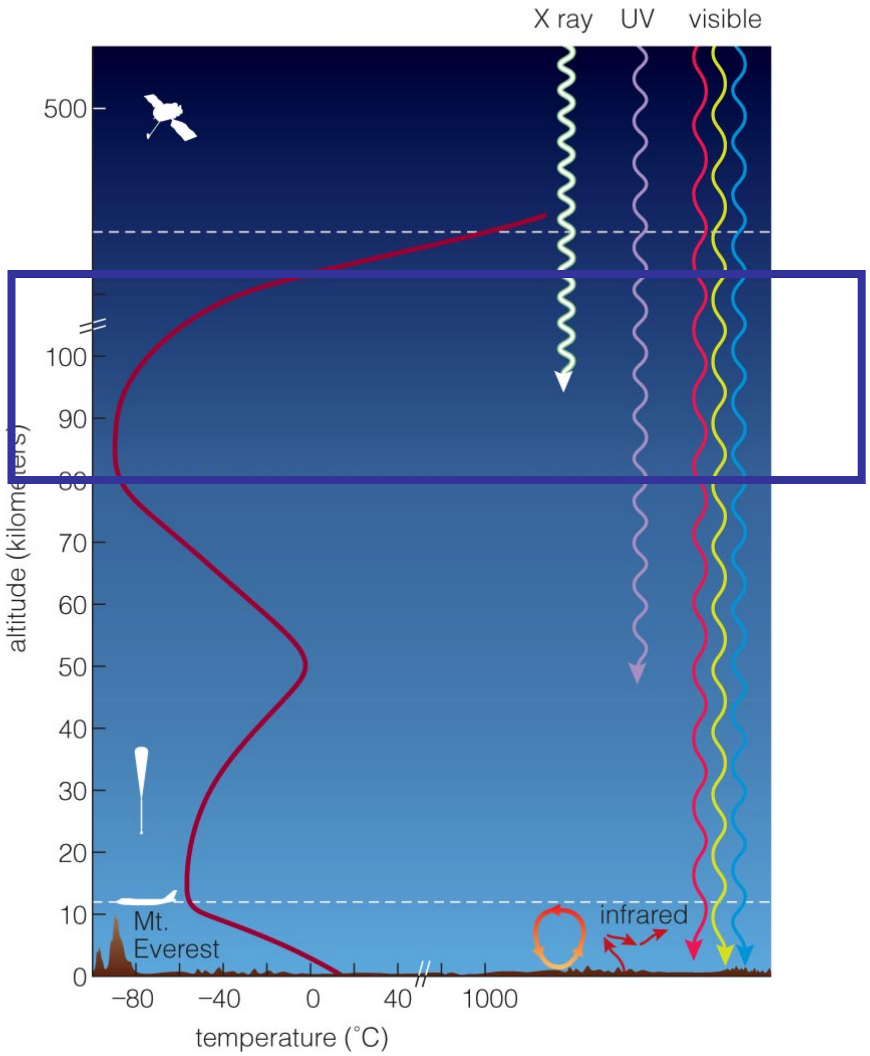
- **Troposphere:** lowest layer of Earth's atmosphere
- Temperature drops as you go upwards.
- Very bottom part is warmed by infrared light from surface

Earth's Atmospheric Structure



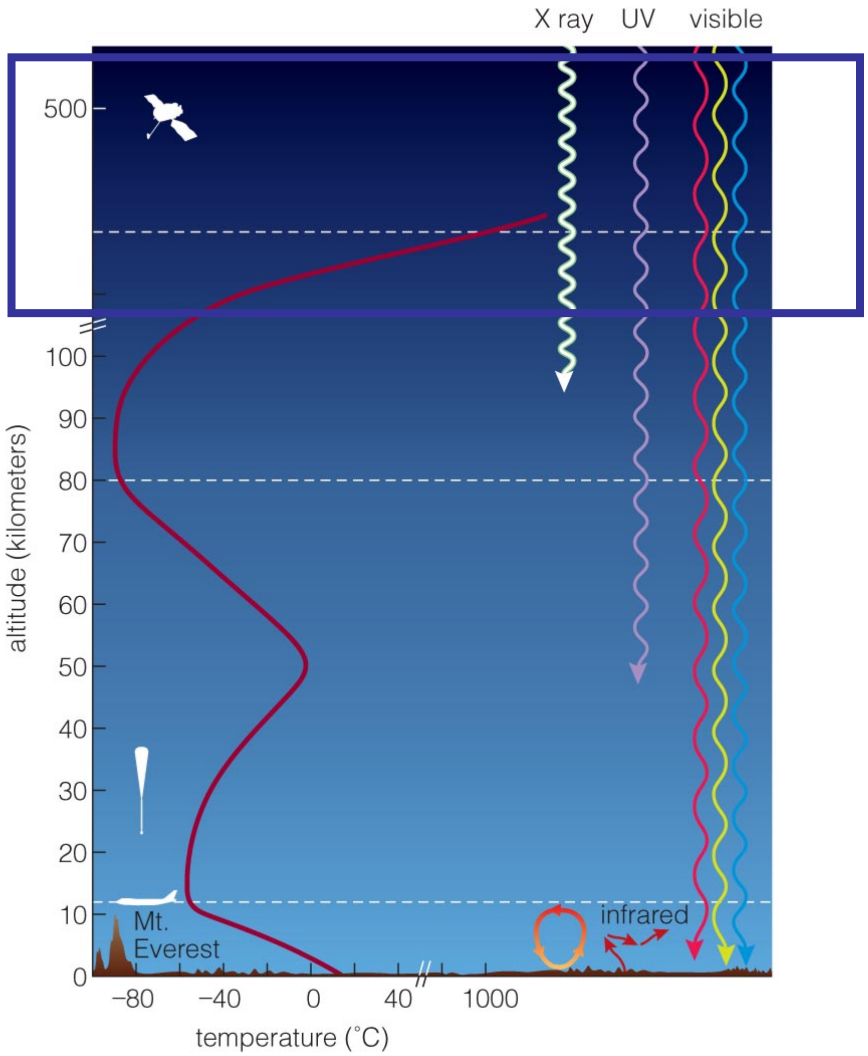
- **Stratosphere:** layer above the troposphere
- As you go upwards, Ttmperature rises with altitude in lower part, drops with altitude in upper part.
- Warmed by absorption of ultraviolet sunlight

Earth's Atmospheric Structure



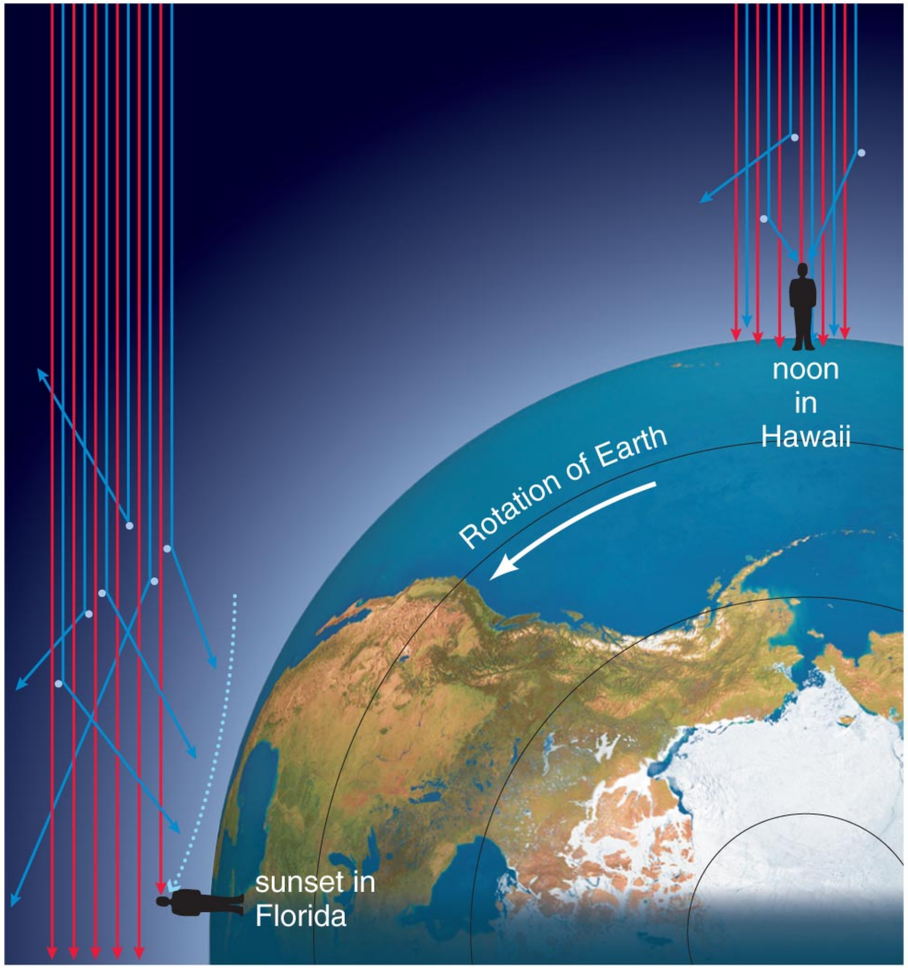
- **Thermosphere:** layer at about 100 kilometers altitude
- Temperature rises as you go up.
- X rays and ultraviolet light from the Sun heat and ionize gases.

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

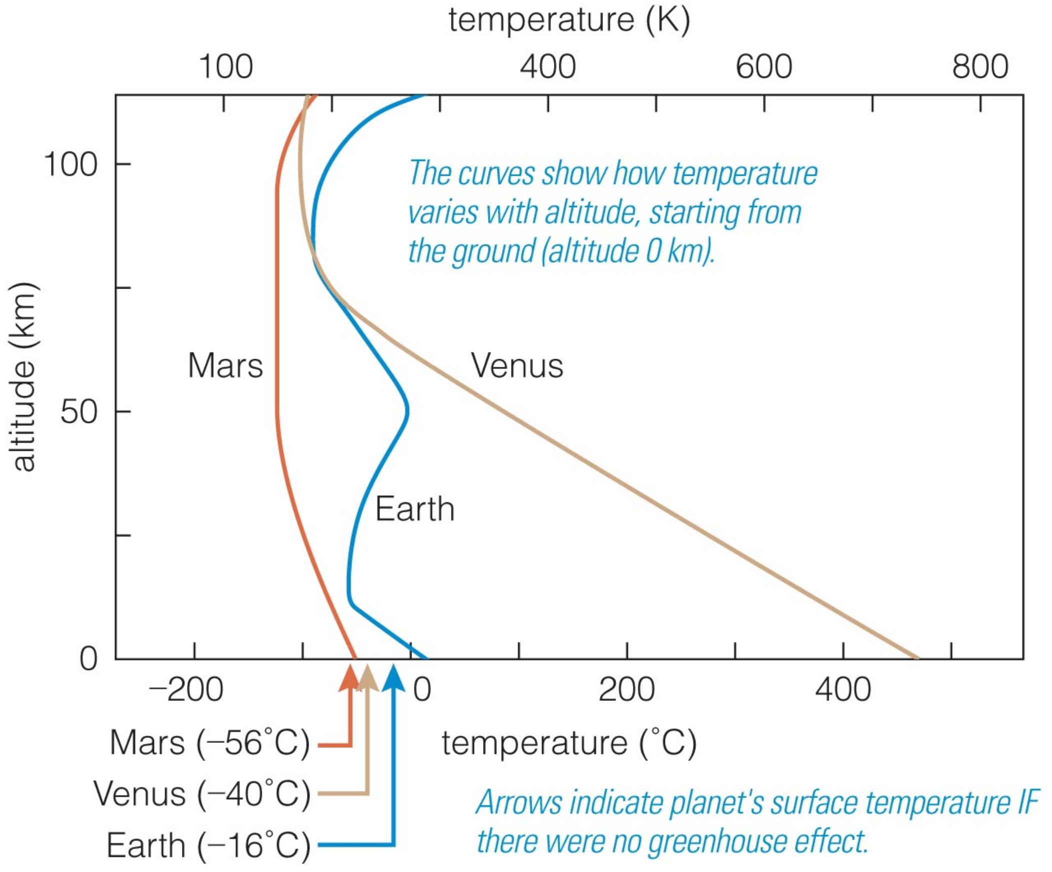


Molecules in the atmosphere scatter light. Blue light scattered most, red scattered less.

Atmosphere scatters blue light from Sun, making it appear to come from different directions.

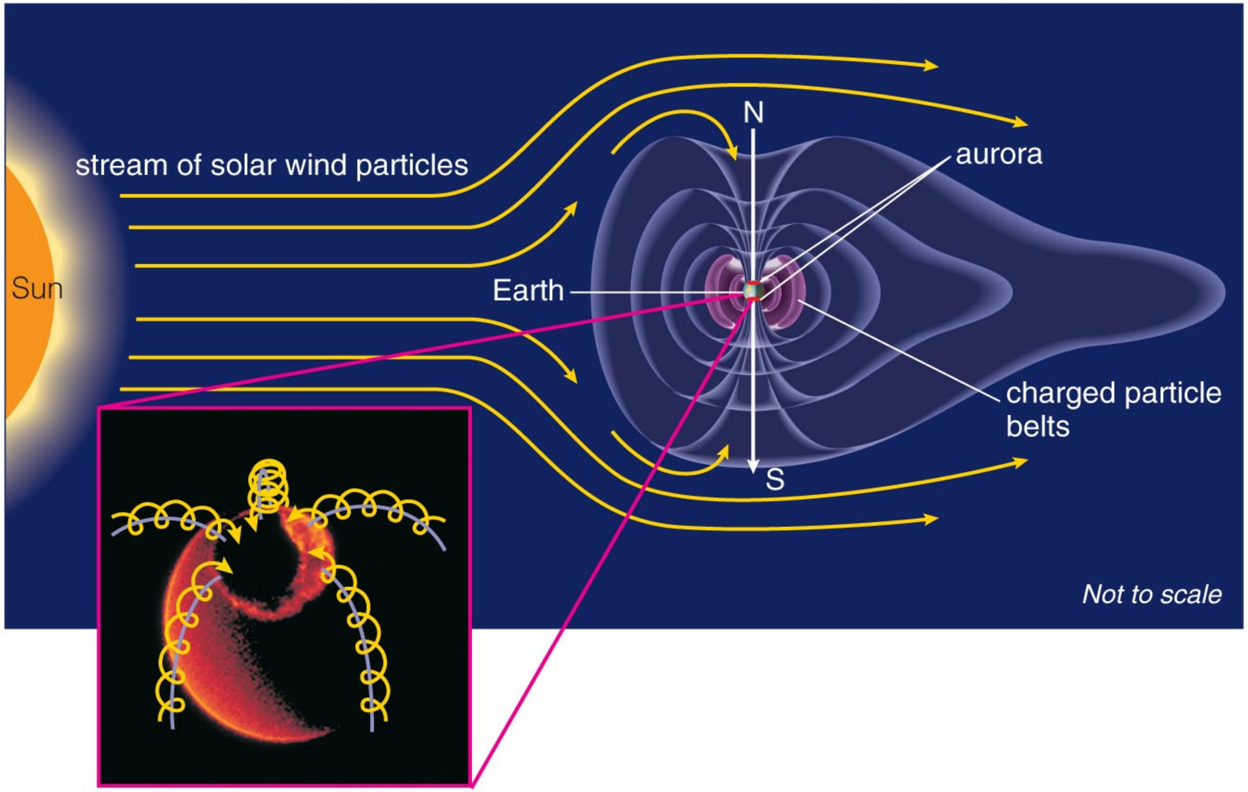
Sunsets are red because red light scatters less.

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.

Earth's Magnetosphere



- High energy charged particles from Sun can’t ”cross” magnetic field lines, must stream along them
- Earth’s magnetic field diverts these particles either around the Earth or towards the poles.

Aurora

b This photograph shows the aurora near Yellowknife, Northwest Territories, Canada. In a video, you would see these lights dancing about in the sky.

- Charged particles from solar wind ionize air molecules the upper atmosphere near magnetic poles. When they recombine, they emit light via emission lines.
- Aurora video
- Aurora forecasts: spaceweather.com

What have we learned?

- **What is an atmosphere?**
  – A layer of gas that surrounds a world
- **How does the greenhouse effect warm a planet?**
  – Atmospheric molecules allow visible sunlight to warm a planet's surface but absorb infrared photons, trapping the heat.
- **Why do atmospheric properties vary with altitude?**
  – They depend on how atmospheric gases interact with sunlight at different altitudes.

10.2 Weather and Climate

- Our goals for learning:
  - **What creates wind and weather?**
  - **What factors can cause long-term climate change?**
  - **How does a planet gain or lose atmospheric gases?**

What creates wind and weather?

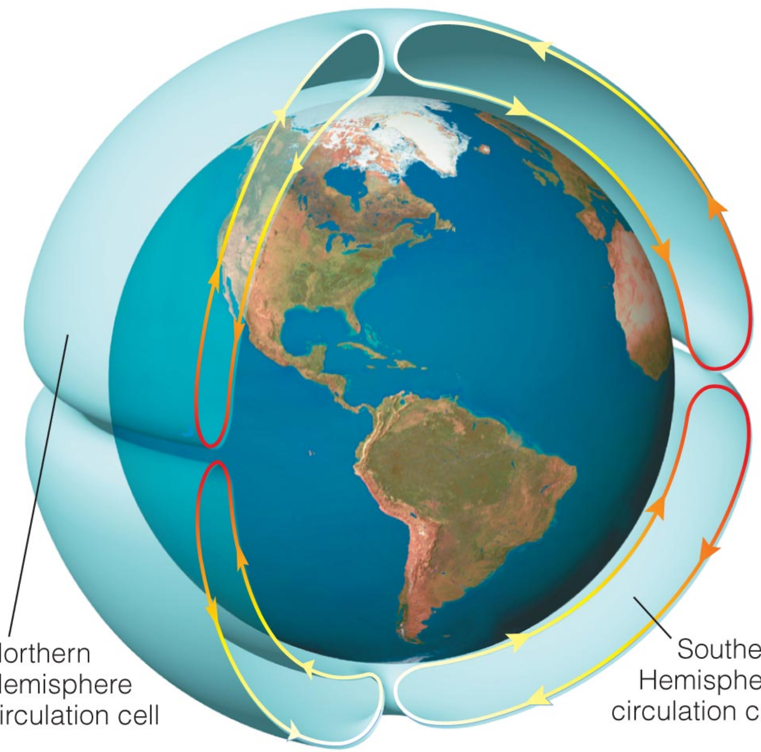
Weather and Climate

- **Weather** is the ever-varying combination of wind, clouds, temperature, and pressure.
  - Local complexity of weather makes it difficult to predict.
- **Climate** is the long-term average of weather.
  - Long-term stability of climate depends on global conditions and is more predictable.

Global Wind Patterns

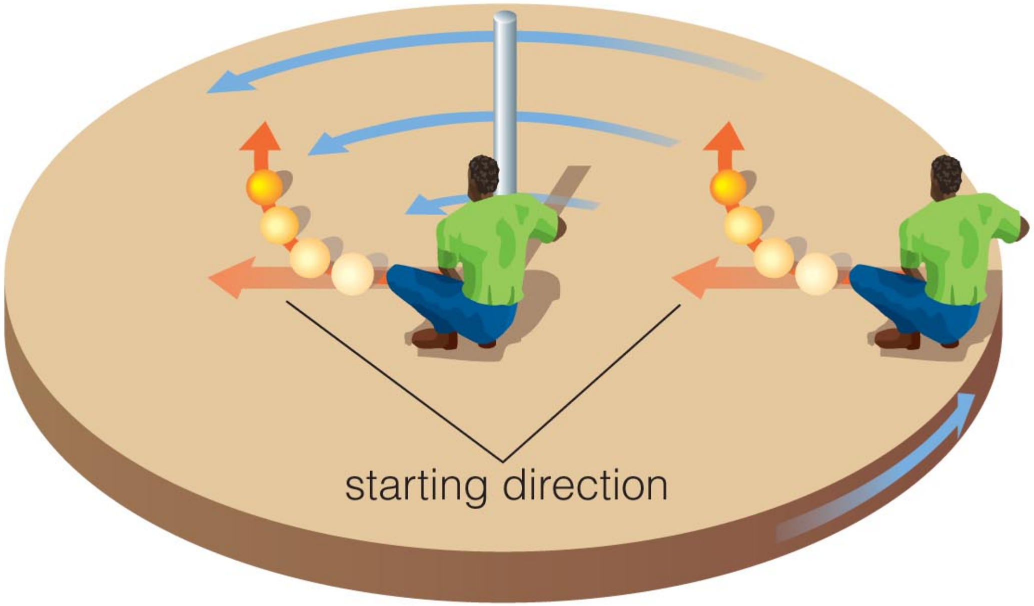
- Global winds blow in distinctive patterns:
  - Equatorial: E to W
  - Mid-latitudes: W to E
  - High latitudes: E to W

Circulation Cells: No Rotation



- Heated air rises at equator.
- Cooler air descends at poles.
- Without rotation, these motions would produce two large circulation cells.

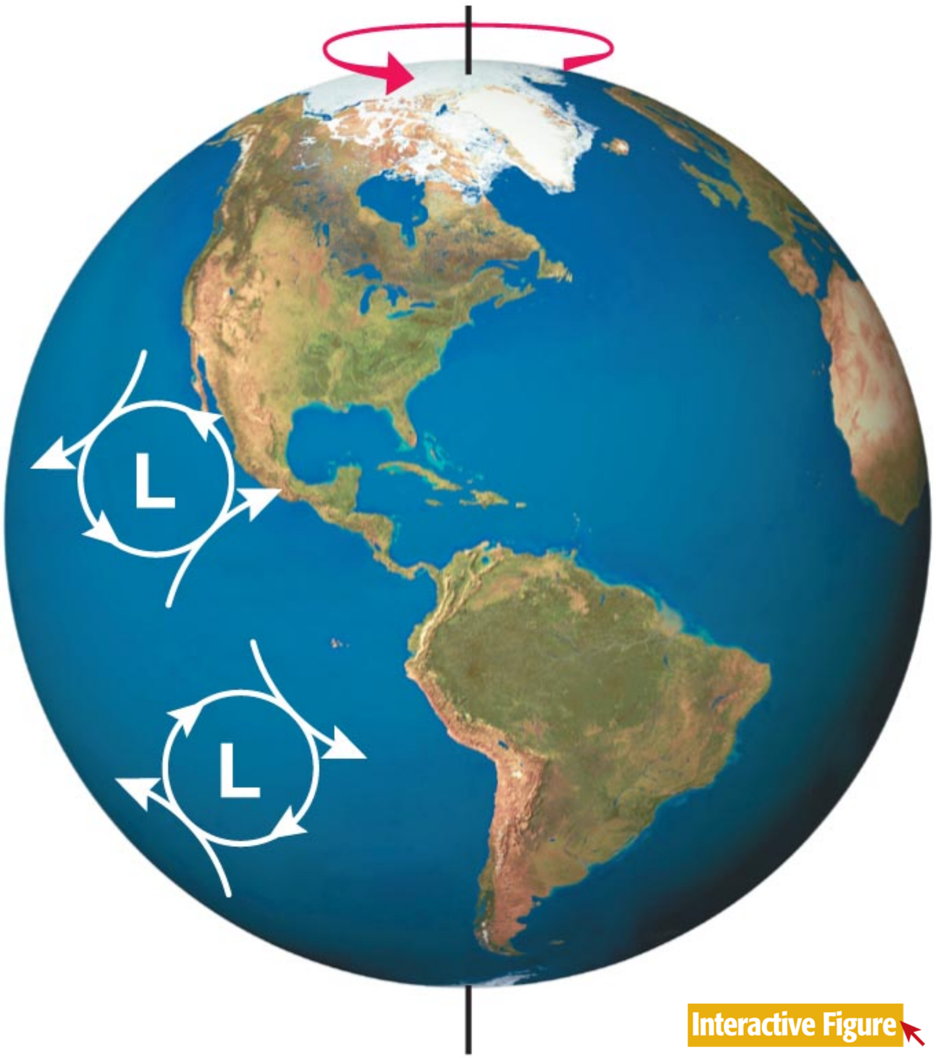
Coriolis Effect



Online Demos
- Demo 1
- Demo 2

- Conservation of angular momentum causes a ball's apparent path on a spinning platform to change direction.

Coriolis Effect on Earth



- Air moving from a pole to the equator is going farther from Earth's axis and begins to lag behind Earth's rotation.
- Air moving from the equator to a pole moves closer to the axis and travels ahead of Earth's rotation.

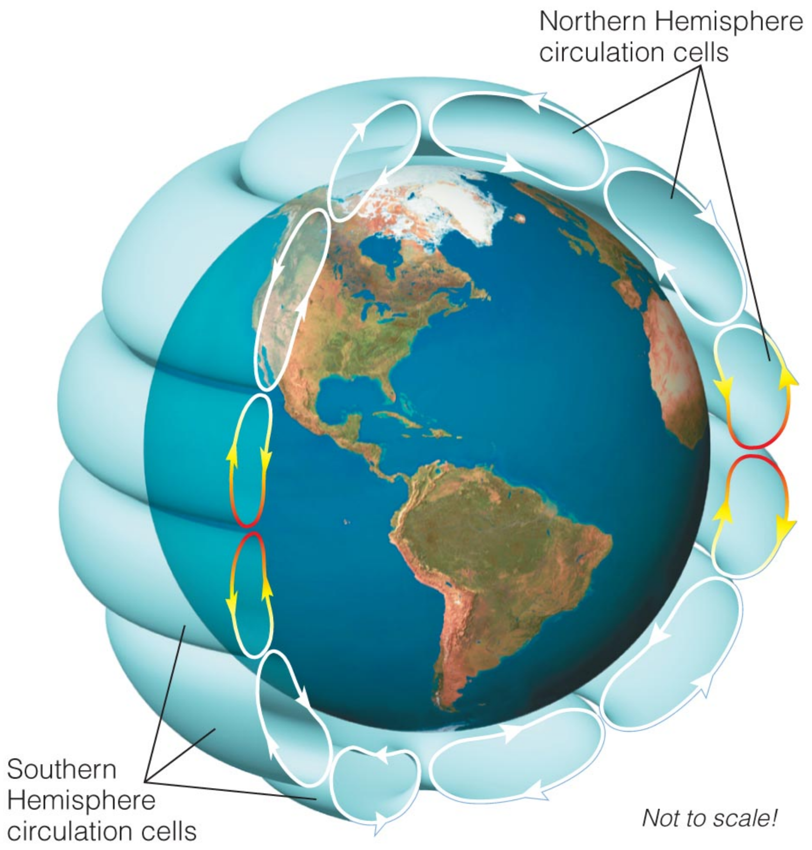
Coriolis Effect on Earth

Conservation of angular momentum causes large storms to swirl.

Direction of circulation depends on hemisphere:

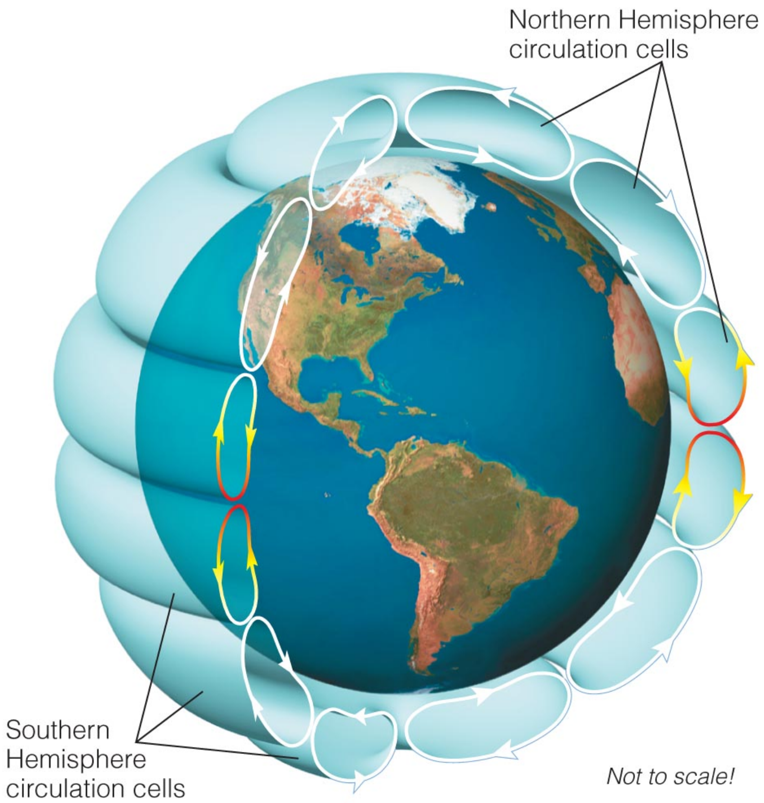
- N: counterclockwise
- S: clockwise

Circulation Cells with Rotation



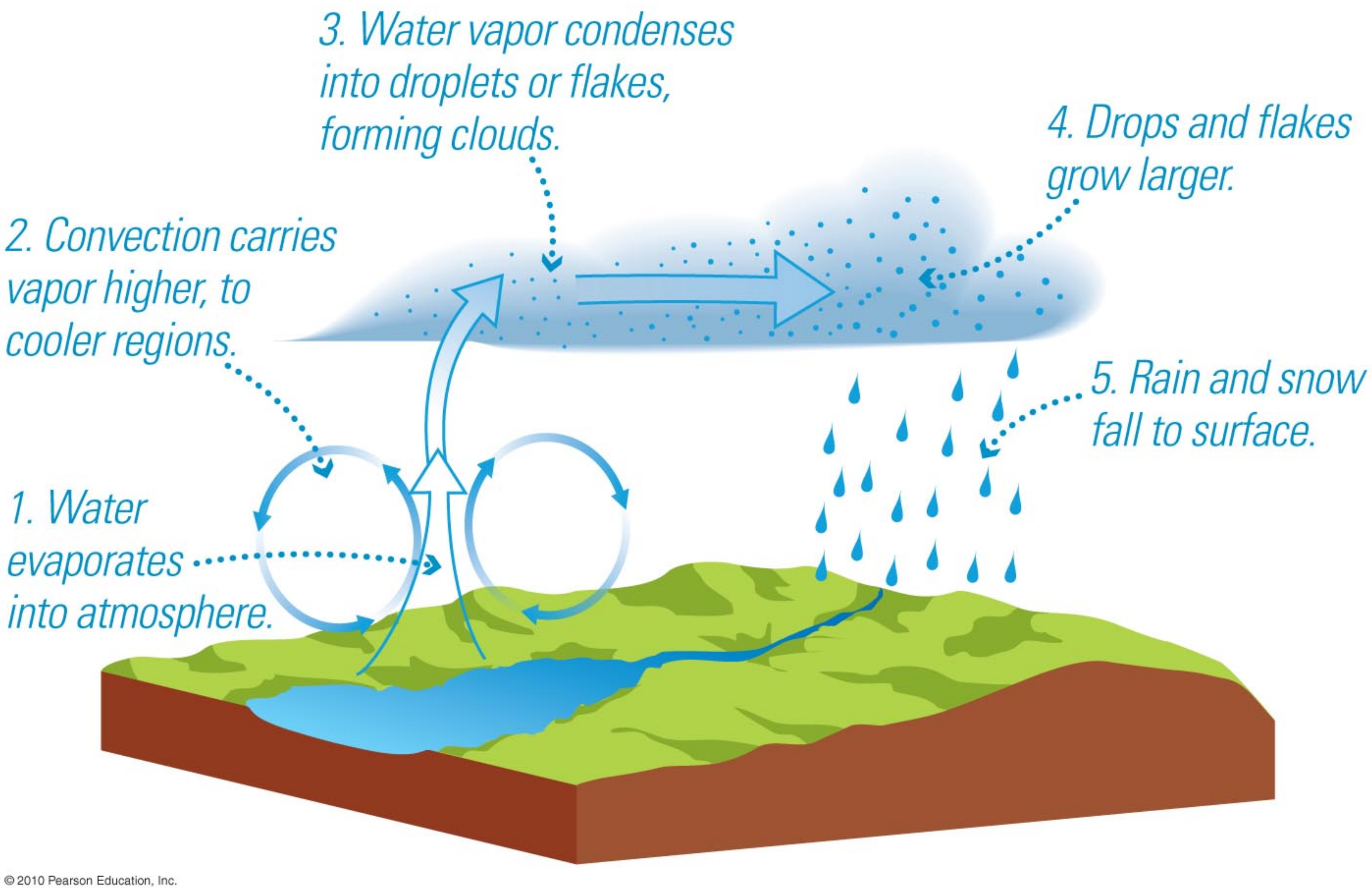
- Coriolis effect deflects north-south winds into east-west winds.
- Deflection breaks each of the two large "no-rotation" cells into three smaller cells.

Prevailing Winds

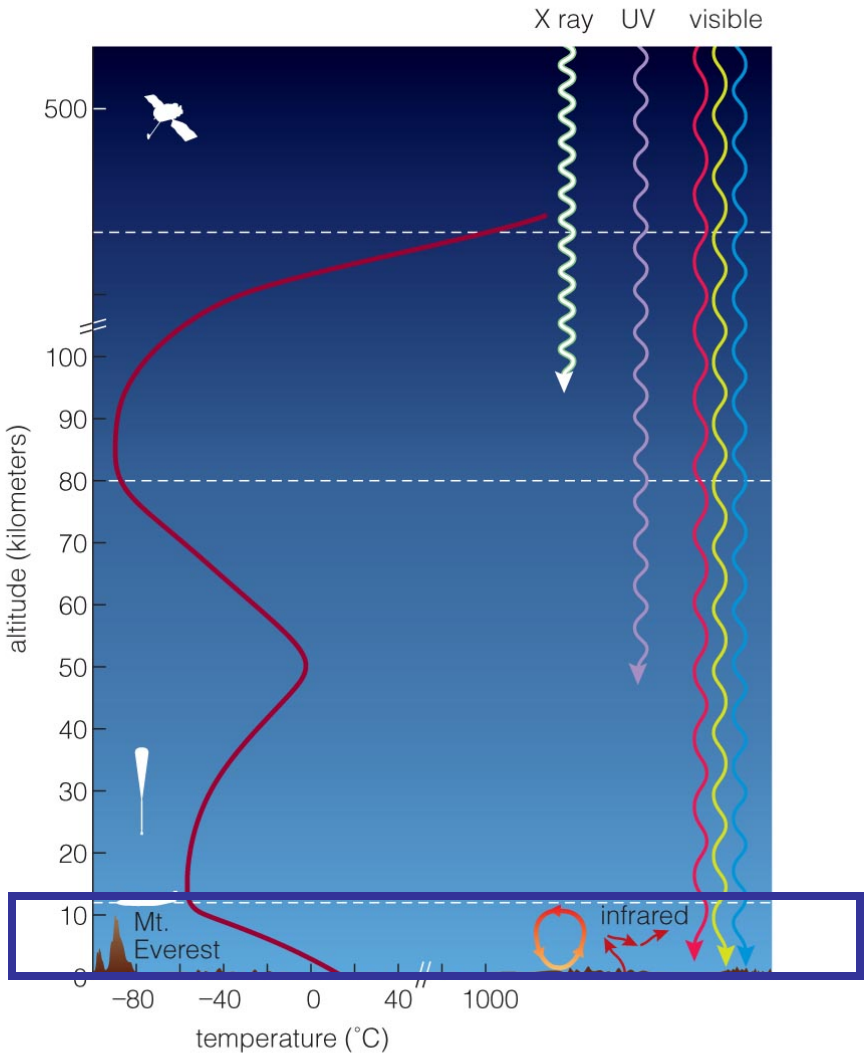


- Prevailing surface winds at mid-latitudes blow from W to E because the Coriolis effect deflects the S to N surface flow of mid-latitude circulation cells.

Clouds and Precipitation



Earth's Atmospheric Structure



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