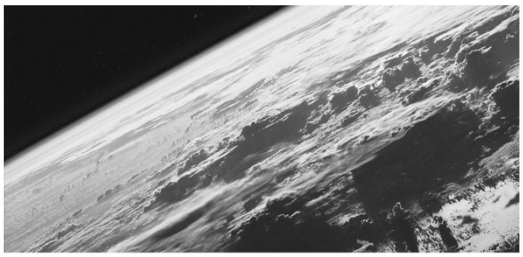
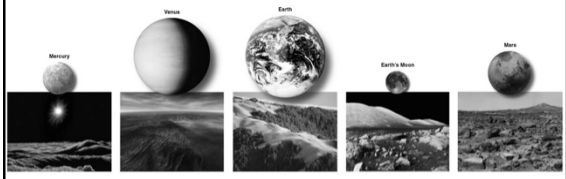
Chapter 10
Planetary Atmospheres:
Earth and the Other Terrestrial Worlds

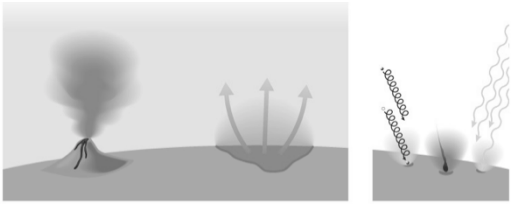


What is an atmosphere?



An atmosphere is a layer of gas that surrounds a world

Sources of Gas



Outgassing from volcanoes

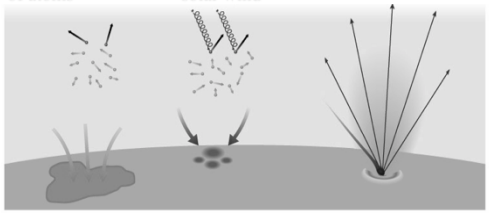
Evaporation of surface liquid; sublimation of surface ice

Impacts of particles and photons eject small amounts

Losses of Gas

Thermal escape of atoms

Sweeping by solar wind

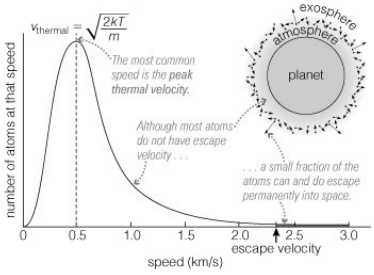


Condensation onto surface

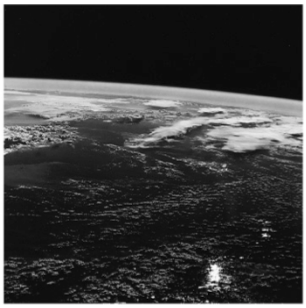
Chemical reactions with surface

Large impacts blast gas into space

Thermal Escape



Earth's Atmosphere



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

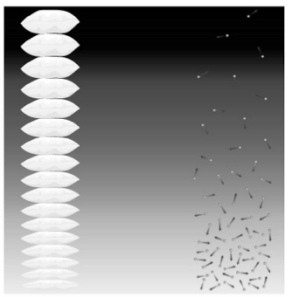
Atmospheric Pressure

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

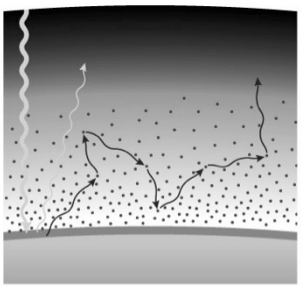


- Pressure and density decrease with altitude because the weight of overlying layers is less
- Earth's pressure at sea level is 1 bar (15 lbs per sq. inch)

Planetary Temperature

- Determined by balance between the energy of sunlight it absorbs and the energy of outgoing thermal radiation
- Hotter when closer to the Sun
- A planet's *albedo* is the fraction of incoming sunlight it reflects
- Planets with low albedo absorb more sunlight, leading to hotter temperatures
- Clouds tend to increase albedo

Greenhouse Effect



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

Thought Question

If Earth didn't have an atmosphere, what would happen to its temperature?

a) It would go up a little.
b) It would go up a lot.
c) It would go down a little.
d) It would go down a lot.
e) It would not change.

Thought Question

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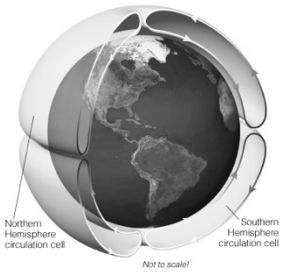
Effects of Atmospheres

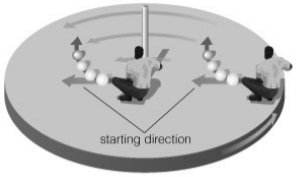
- Create pressure that determines whether liquid water can exist on surface
- Absorb and scatter light
- Interact with solar wind to create a protective magnetosphere
- Can make planetary surfaces warmer through greenhouse effect
- Create wind, **weather** (fast), **climate** (slow)

Circulation Cells: No Rotation



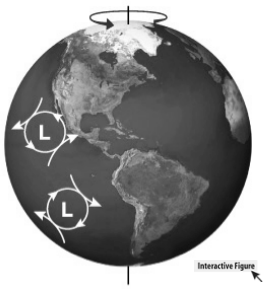
- Heated air rises at equator
- Cooler air descends at poles
- Without rotation, these motions would produce two large circulation cells

Coriolis Effect



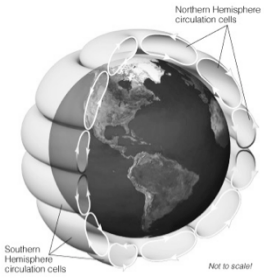
- Conservation of angular momentum causes a ball's apparent path on a spinning platform to change direction

Coriolis Effect on Earth



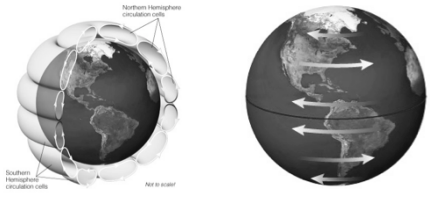
- Air moving from pole to equator is going farther from axis and begins to lag Earth's rotation
- Air moving from equator to pole goes closer to axis and moves ahead of Earth's rotation

Circulation Cells with Rotation



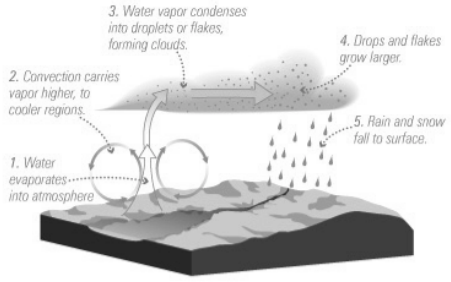
- Coriolis effect deflects north-south winds into east-west winds
- Deflection breaks each of the two large "no-rotation" cells breaks into three smaller cells

Prevailing Winds



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

Clouds and Precipitation



What factors can cause long-term climate change?

Brightening of Sun

Change in albedo

Change in tilt

Change in greenhouse effect

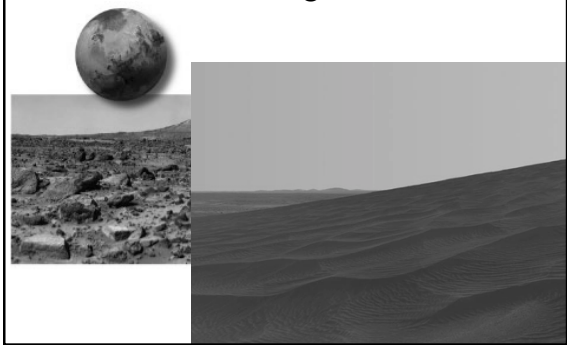
Atmospheres of the Terrestrial Planets

Table 10.1 Atmospheres of the Terrestrial Worlds

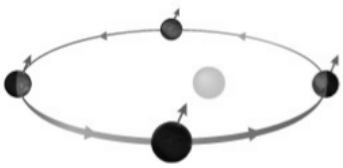
World	Composition of Atmosphere	Surface Pressure*	Average Surface Temperature	Winds, Weather Patterns	Clouds, Hazes
Mercury	helium, sodium, oxygen	10^{-14} bar	day: 425°C (797°F); night: −175°C (−283°F)	none: too little atmosphere	none
Venus	96% carbon dioxide (CO_2) 3.5% nitrogen (N_2)	90 bars	470°C (878°F)	slow winds, no violent storms, acid rain	sulfuric acid clouds
Earth	77% nitrogen (N_2) 21% oxygen (O_2) 1% argon H_2O (variable)	1 bar	15°C (59°F)	winds, hurricanes, rain, snow	H_2O clouds, pollution
Moon	helium, sodium, argon	10^{-14} bar	day: 125°C (257°F); night: −175°C (−283°F)	none: too little atmosphere	none
Mars	95% carbon dioxide (CO_2) 2.7% nitrogen (N_2) 1.6% argon	0.007 bar	−50°C (−58°F)	winds, dust storms	H_2O and CO_2 clouds, dust

* 1 bar = the pressure at sea level on Earth.

Climate Change on Mars

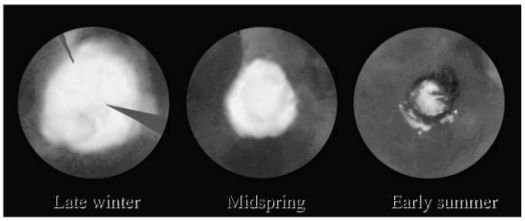


Seasons on Mars



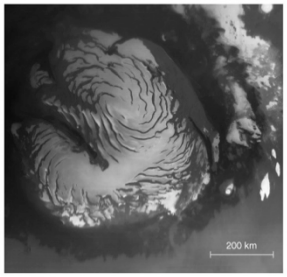
- Axial tilt plus eccentricity of Mars's orbit makes seasons more extreme in the southern hemisphere

Polar Ice Caps of Mars



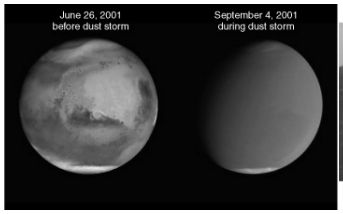
- Carbon dioxide ice of polar cap sublimates as summer approaches and condenses at opposite pole

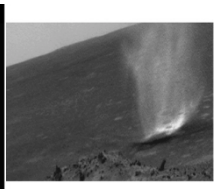
Polar Ice Caps of Mars



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

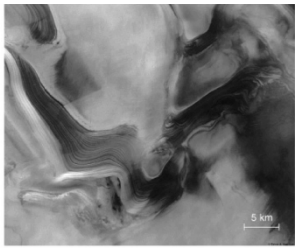
Dust Storms on Mars





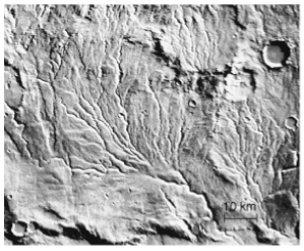
- Seasonal winds can drive dust storms on Mars
- Dust in the atmosphere sometimes making the sky look brownish-pink

Changing Axis Tilt



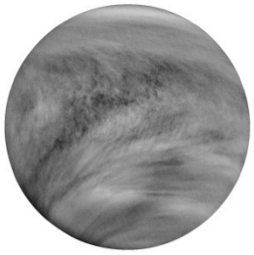
- Mars's axis tilt ranges from 0° to 60° over long time periods
- Variations cause dramatic climate changes
- Produce alternating layers of ice and dust in polar caps

Climate Change on Mars: Wet to dry



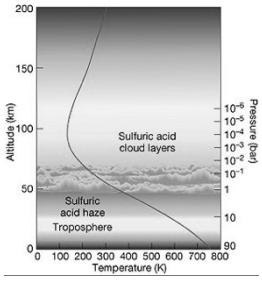
- Mars has not had widespread surface water for 3 billion years
- Greenhouse effect probably kept surface warmer before that
- Somehow Mars lost most of its atmosphere

Atmosphere of Venus



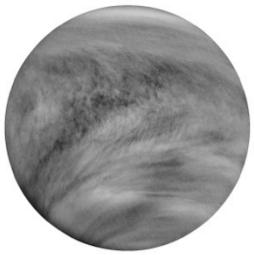
- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times Earth's
- 880 F at surface
- Slow rotation produces very weak Coriolis effect and little weather

Atmosphere of Venus



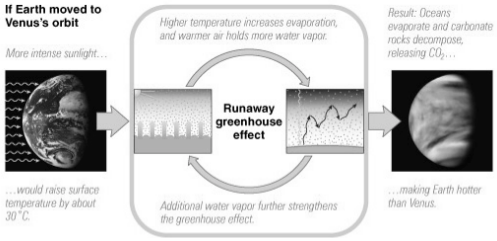
- Reflective clouds contain droplets of sulfuric acid
- Upper atmosphere has fast winds that remain unexplained

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

Runaway Greenhouse Effect



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

Thought Question

What is the main reason why Venus is hotter than Earth?

a) Venus is closer to the Sun than Earth.
b) Venus is more reflective than Earth.
c) Venus is less reflective than Earth.
d) Greenhouse effect is much stronger on Venus than on Earth.
e) Human activity has led to declining temperatures on Earth.

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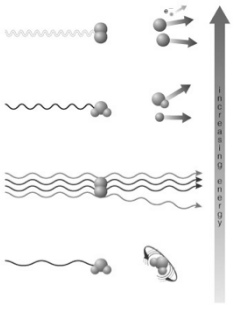
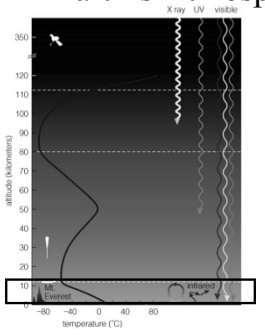
Light's Effects on Atmosphere



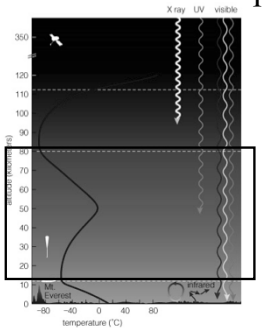
- **Ionization:** Removal of an electron
- **Dissociation:** Destruction of a molecule
- **Scattering:** Change in photon's direction
- **Absorption:** Photon's energy is absorbed

Earth's Atmospheric Structure



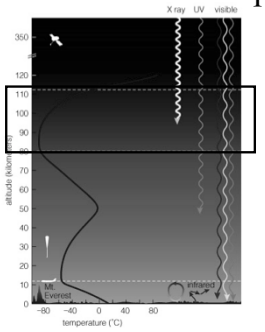
- **Troposphere:** lowest layer of Earth's atmosphere
- Temperature drops with altitude
- Warmed by infrared light from surface and convection

Earth's Atmospheric Structure



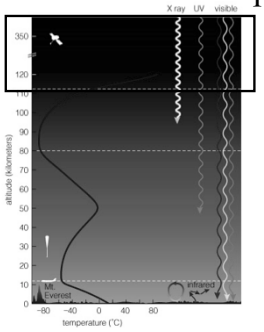
- **Stratosphere:** Layer above the troposphere
- Temperature rises with altitude in lower part, drops with altitude in upper part
- Warmed by absorption of ultraviolet sunlight

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

Four Important Questions

- Why did Earth retain most of its outgassed water?
- Why does Earth have so little atmospheric carbon dioxide, unlike Venus?
- Why does Earth's atmosphere consist mostly of nitrogen and oxygen?
- Why does Earth have a UV-absorbing stratosphere?

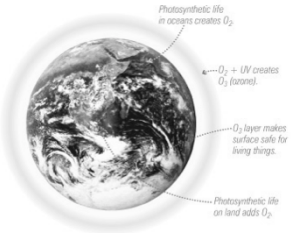
Earth's Water and CO_2

- Earth's temperature remained cool enough for liquid oceans to form
- Oceans dissolve atmospheric CO_2, enabling carbon to be trapped in rocks

Nitrogen and Oxygen

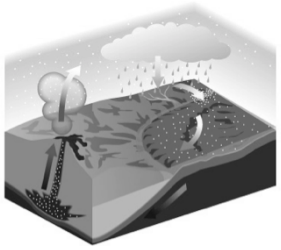
- Most of Earth's carbon and oxygen is in rocks, leaving a mostly nitrogen atmosphere
- Plants release some oxygen from CO_2 into atmosphere
- If all life ceased, oxygen would be gone in 10,000 years

Ozone and the Stratosphere



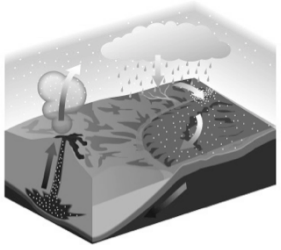
- Ultraviolet light can break up O_2 molecules, allowing ozone (O_3) to form
- Without plants to release O_2, there would be no ozone in stratosphere to absorb UV light (protects life)

Carbon Dioxide Cycle



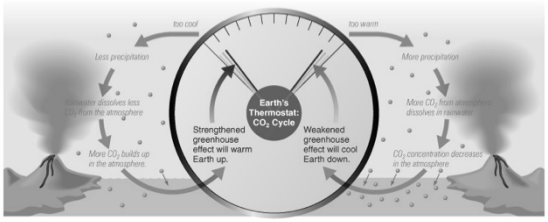
1. Atmospheric CO_2 dissolves in rainwater
2. Rain erodes minerals which flow into ocean
3. Minerals combine with carbon to make rocks on ocean floor

Carbon Dioxide Cycle



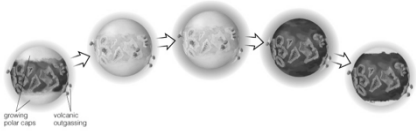
4. Subduction carries carbonate rocks down into mantle
5. Rock melts in the mantle and outgas CO_2 back into atmosphere through volcanoes

Earth's Thermostat



- Cooling allows CO_2 to build up in atmosphere
- Heating causes rain to reduce CO_2 in atmosphere

Long-Term Climate Change



- Changes in Earth's axis tilt might lead to *ice ages*
- Widespread ice tends to lower global temperatures by increasing Earth's reflectivity
- CO_2 from outgassing will build up if oceans are frozen, ultimately raising global temperatures again

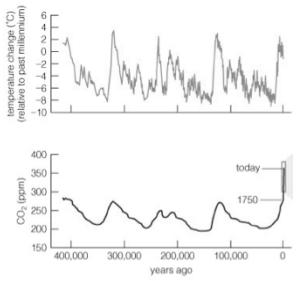
Dangers of Human Activity

- Human-made CFCs in atmosphere destroy ozone, reducing protection from UV radiation
- Human activity is driving many other species to extinction
- Human use of fossil fuels produces greenhouse gases that can cause global warming

Global Warming

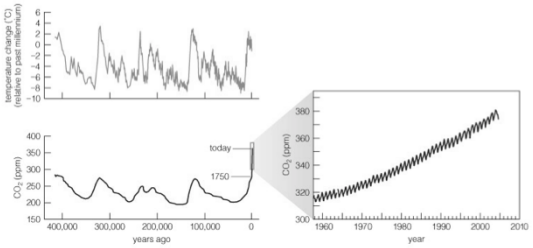
- Earth's average temperature has increased by 0.5°C in past 50 years
- Concentration of CO_2 is rising rapidly
- An unchecked rise in greenhouse gases will eventually lead to global warming

CO_2 Concentration



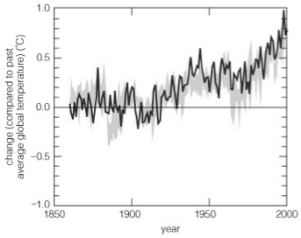
- Global temperatures have tracked CO_2 concentration for last 500,000 years
- Antarctic air bubbles indicate current CO_2 concentration is highest in at least 500,000 years

CO_2 Concentration



- Most of CO_2 increase has happened in last 50 years!

Modeling of Climate Change



- Complex models of global warming suggest that recent temperature increase is indeed consistent with human production of greenhouse gases

Consequences of Global Warming

- Storms more numerous and intense
- Rising ocean levels; melting glaciers
- Uncertain effects on food production, availability of fresh water
- Potential for social unrest

Next time:

- Chapter 11:
  Jovian Planets
  please read pages 309 – 334
  in text.