[16] Planetary Meteorology (10/24/17)

Upcoming Items

1. Homework #7 due now.
2. Homework #8 due in one week.
3. Midterm #2 on Nov 7
4. Read pages 239-240 (magnetic fields) and Ch. 10.6 by next class and do the self-study quizzes.

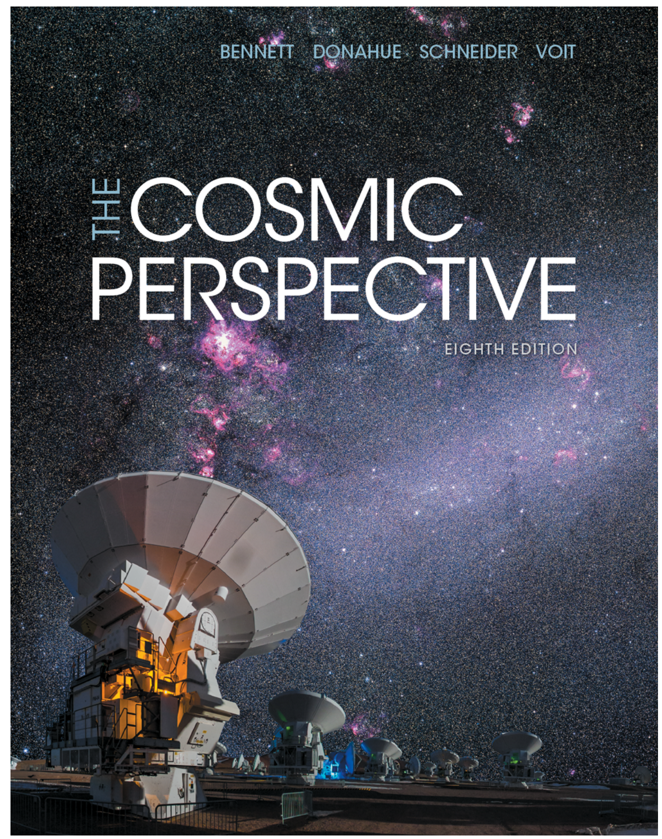
https://3c1703fe8d.site.internapcdn.net/newman/csz/news/800/2016/2-studypinpoin.jpg

LEARNING GOALS

Chapters 10.1–10.2

For this class, you should be able to…

- … *understand the effects of an atmosphere on a planet;*
- … *understand hydrostatic equilibrium;*
- … *determine whether a planet will retain a particular gas for at least 1 Gyr given properties of the planet and star.*



Changes Based on Feedback

- Thanks for your feedback on Friday! Very helpful.
- Most of you seem to be enjoying the class; that's good to hear
- Some think the class is too hard
  A surprising number think the class is too *easy*
  But I don't plan to make it *more* challenging
- Many noted the extra time spent in doing HW online
- Okay, you can submit a scan, or turn in HW in person, but:
  1. HW in person must be by 11:00:00, or point penalty
  2. If scanned or written HW can't be read by Drew, he can and will take significant points off; HW must be legible!
  3. You can still turn HW in online as before

Any astro questions?

Group Q: Effects of Atmospheres

- With your group, list as many distinct effects of atmospheres as possible

Effects of Atmospheres

- They create pressure that determines whether liquid water can exist on surface.
- They absorb and scatter light
  Shield against energetic radiation and particles!
- They create wind, weather, and climate.
- They interact with the solar wind and the planet's magnetic field to create aurorae.
- They can make planetary surfaces warmer through the greenhouse effect.

What is an atmosphere?

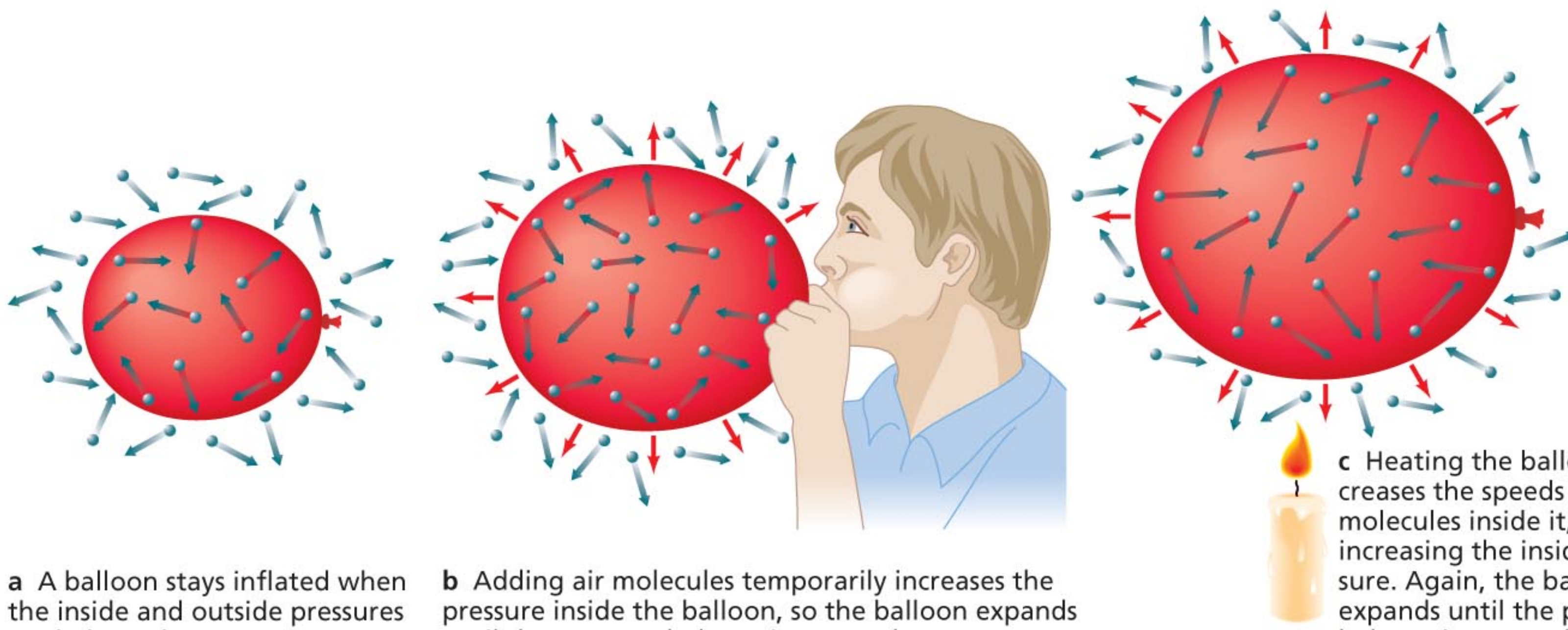
- An atmosphere is a layer of gas that surrounds a world.

Earth's Atmosphere

Education, Inc.

- About 10 km thick.
- Consists mostly of molecular nitrogen (N_2) & oxygen (O_2).
- Why doesn't it go higher?

Atmospheric Pressure



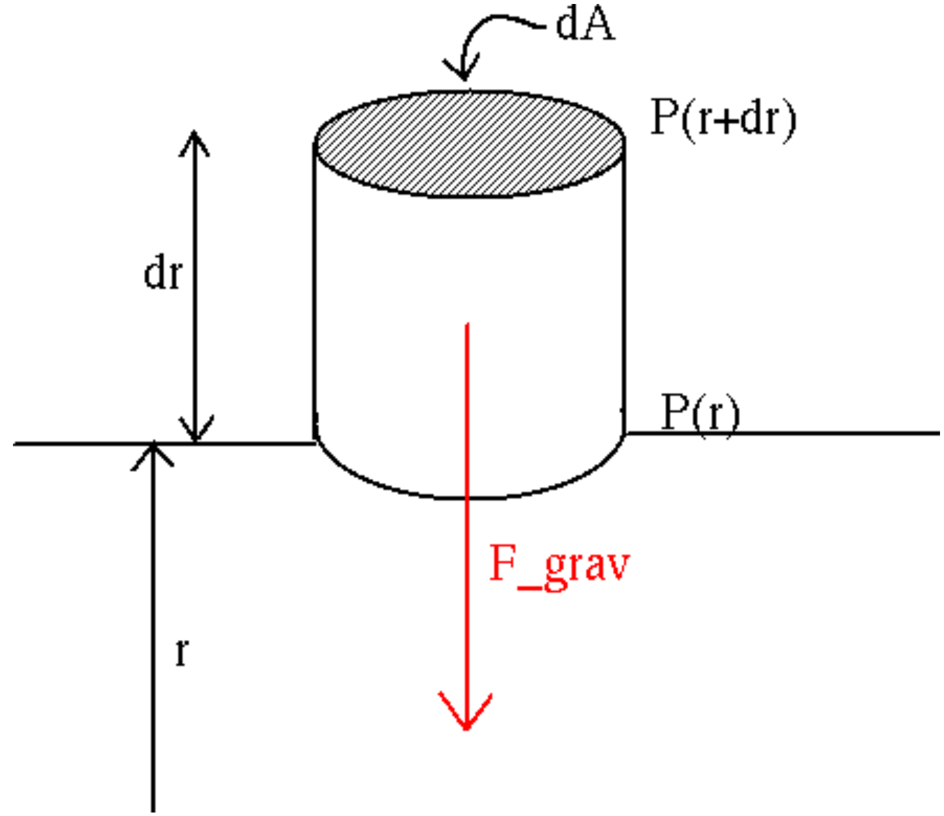
a A balloon stays inflated when the inside and outside pressures are balanced.

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.

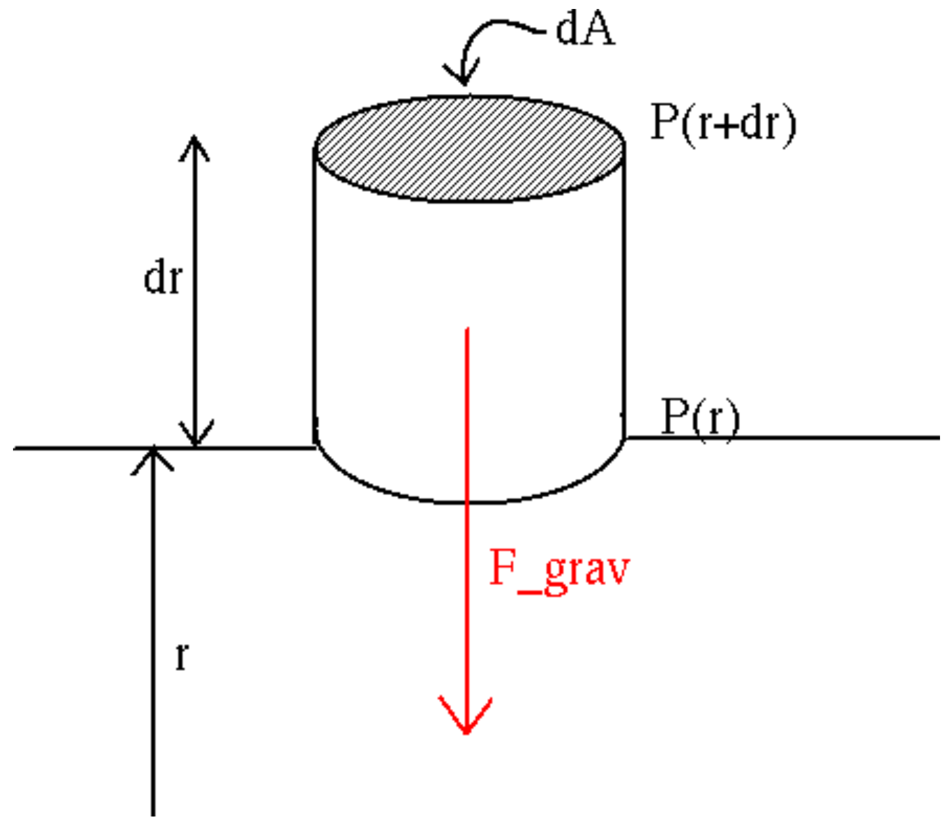
Hydrostatic Equilibrium

- Why doesn't the atmosphere fall down?
- Put another way, what force on the atmosphere opposes gravity?

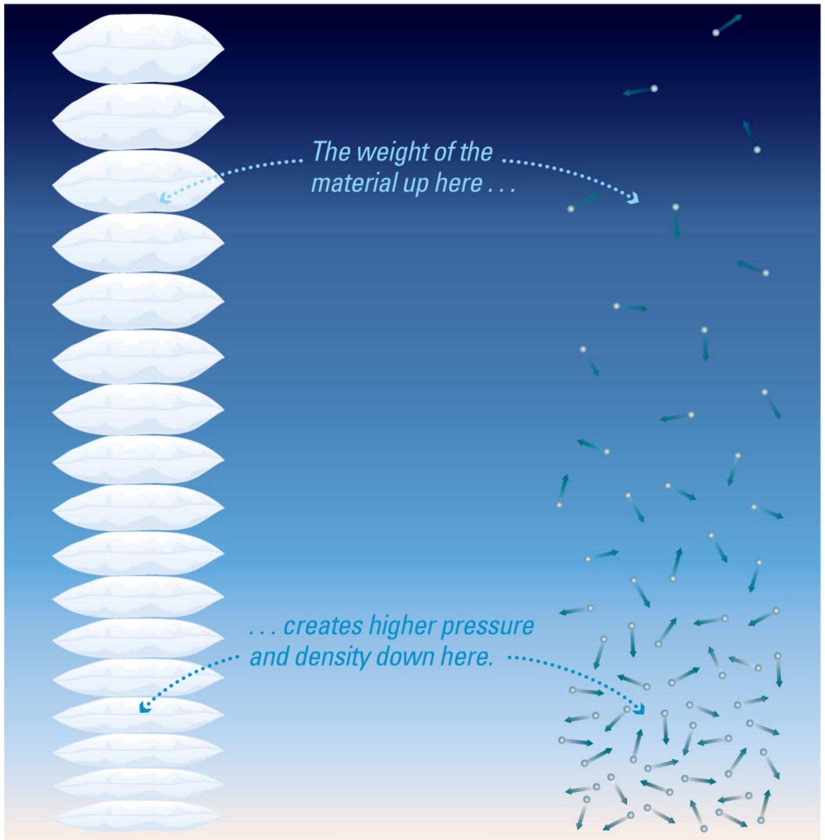


Hydrostatic Equilibrium

- Why doesn't the atmosphere fall down?
- Put another way, what force on the atmosphere opposes gravity?
- The answer is *pressure gradients*
  Pressure below is greater than pressure above
- Thus pressure force is up, which opposes gravity's pull down



Atmospheric Pressure



- Pressure and density decrease with altitude because the weight of overlying layers is less.
- Earth's atmospheric pressure at sea level is:
  - 1.01×10^5 N/m^2 (101.325 kPa).
  - 14.7 lb per sq. inch.
  - 1.01 bar.

Equation of Hydrostatic Equilibrium

- Suppose the pressure is a function of the height, which we represent by r
- Let the density be ρ, and the gravitational acceleration be g
- Then the balance between the gravitational force and the force from the pressure gradient is encapsulated in the *equation of hydrostatic equilibrium*

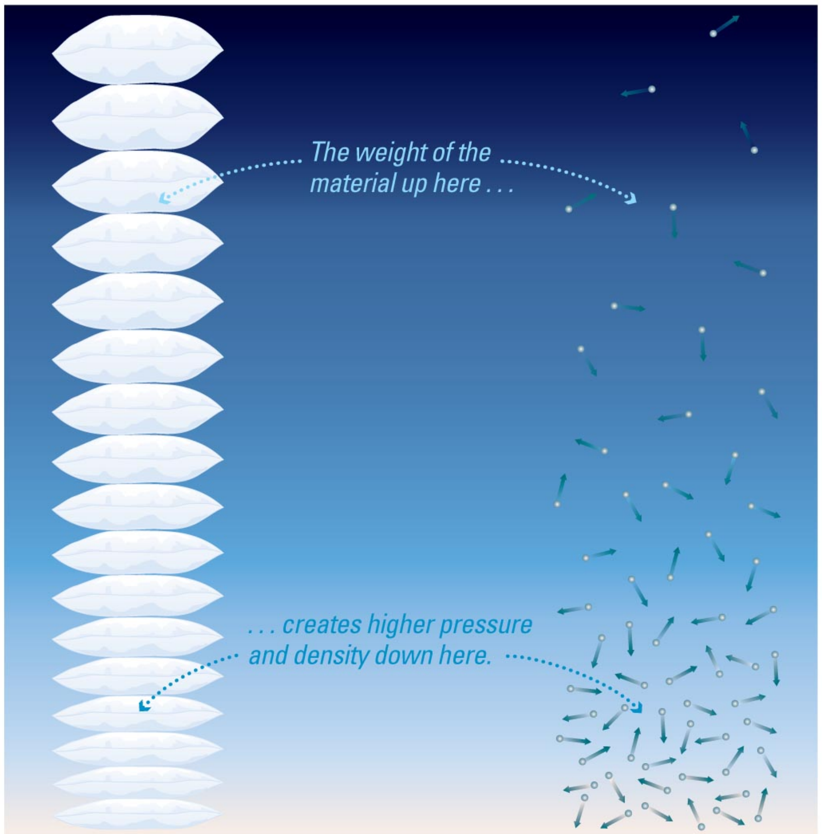
$$dP/dr = -\rho g$$

- The derivation of this equation is on the ELMS page (look in “Files”, “derivations”, “hydrostatic”)
  You are responsible for reading and understanding, i.e., in homework or exams I might assume you know this
- What questions do you have about the meaning of the eqn?

Thinking about it...

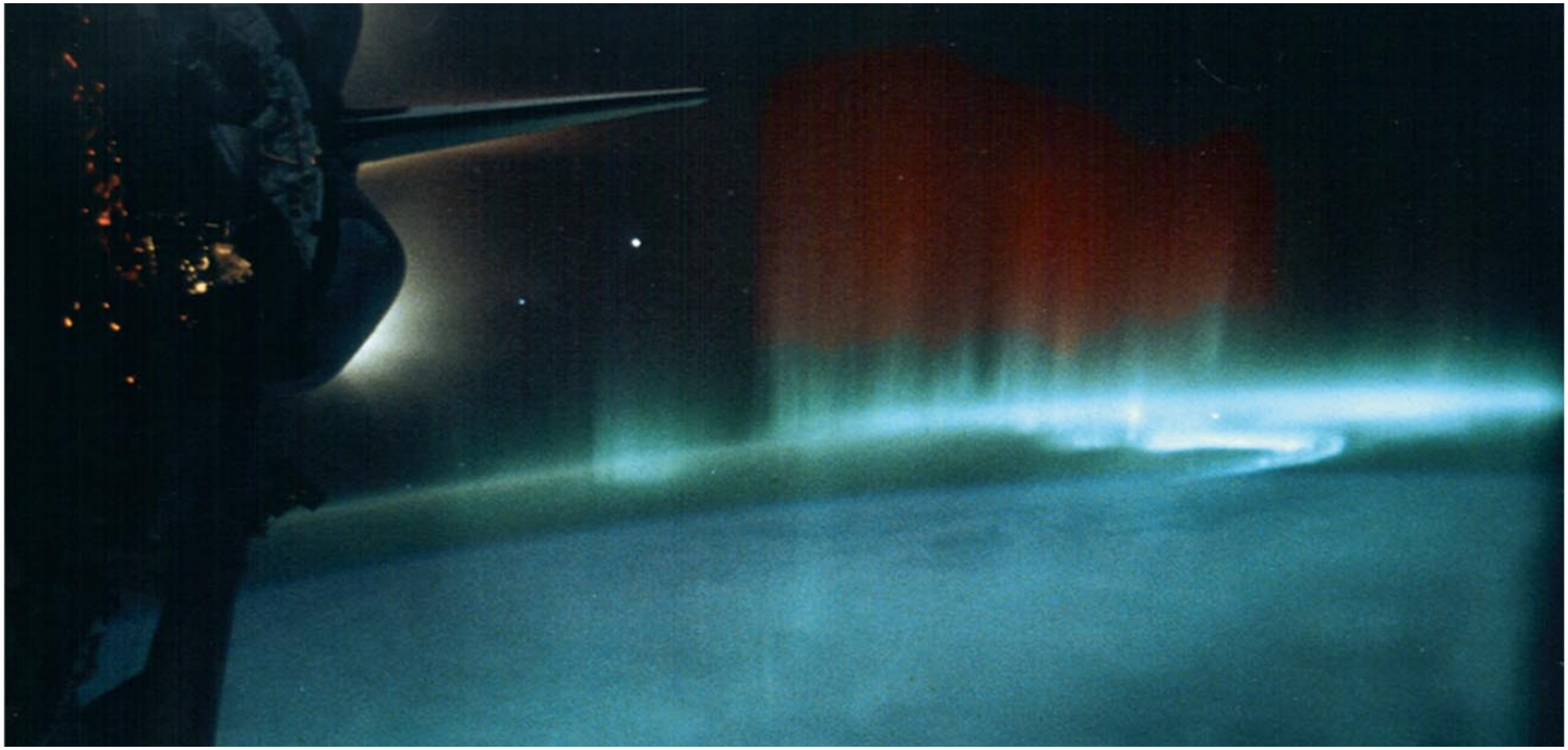
- Will hydrostatic equilibrium principles also apply to water, rock, etc., or should it just apply to the atmosphere?

Where does an atmosphere end?



- There is no clear upper boundary.
- Most of Earth's gas is less than 10 km from surface, but small amount extends to more than 100 km.
- Altitudes above 100 km are considered "space."

Where does an atmosphere end?



- Small amounts of gas are present even above 300 km (interplanetary medium).

Estimating the Pressure Profile

- For an idealized atmosphere,

$$P(r) \cong P_0 e^{-r/H}$$

- where
  - r = altitude (m)
  - P_0 = pressure at “sea” level (Pa)
  - $H = kT/mg$ = scale height (m)
  - T = temperature, assumed constant (Kelvin)
  - m = mean molecular mass of atmospheric constituents (kg)
  - g = surface gravity (m/s^2).
- For Earth, $P_0 = 1$ atm, $H \sim 8$ km.
- Derivation of pressure profile: ELMS->”Files”-> ”derivations”->”exponential”

- Illustration of brightness scaled by albedo:
  - Enceladus 99%.
  - Earth 31%.
  - Moon 14%.
  - Comet 5%.

We will use α to represent albedo

Equilibrium Temperature and Thermal Escape

- Recall the temperature T of a gas is related to the mean speed v_{th} of its constituents. In 1-D,

$$\frac{1}{2}mv_{\text{th}}^2 = k_B T, \text{ so } v_{\text{th}} = \sqrt{\frac{2k_B T}{m}} \quad (m = \text{particle mass}).$$

- The gas temperature will be approximately equal to the equilibrium temperature T_{eq} of the planet, given at dist d by

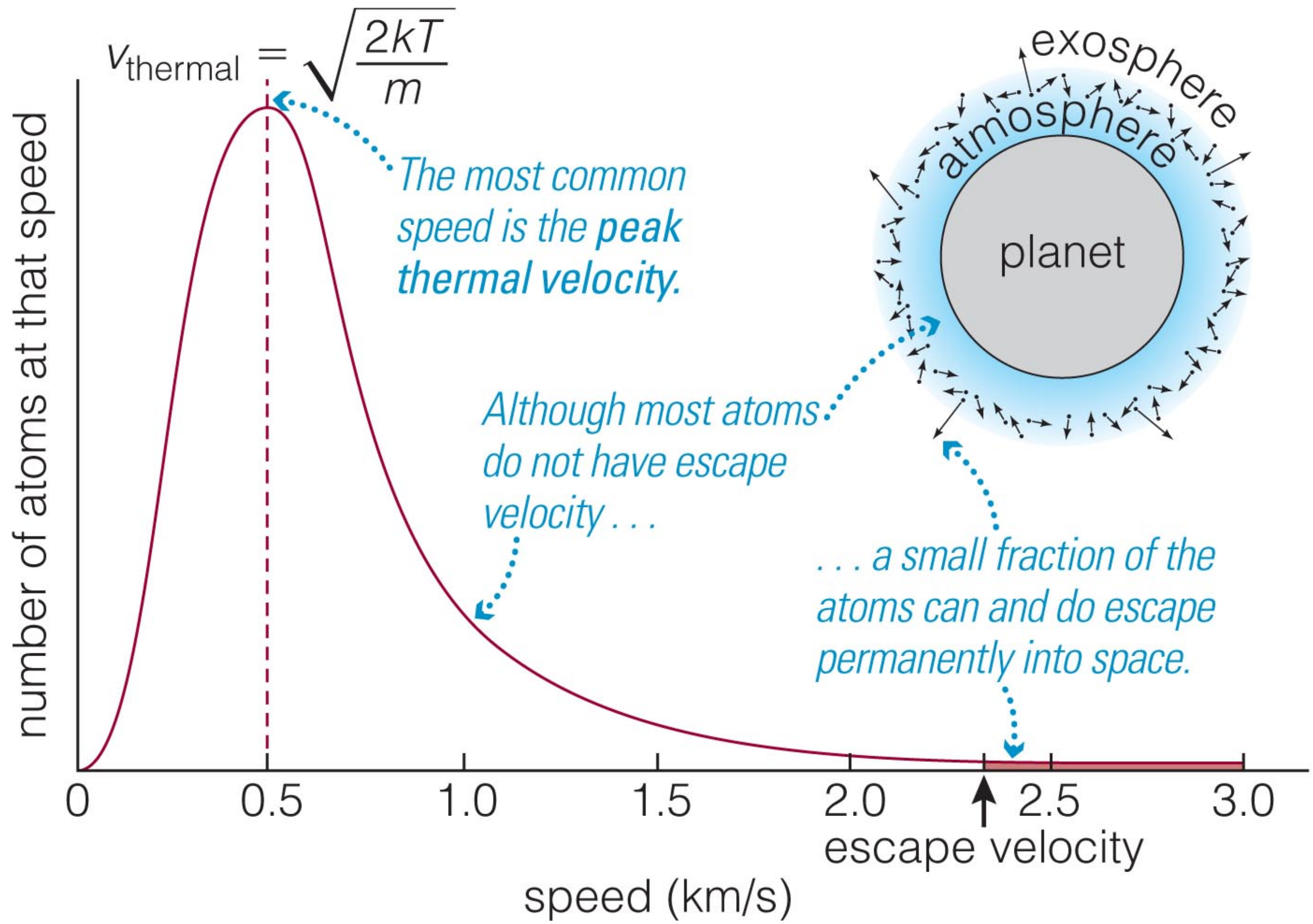
$$T_{\text{eq}} = \left[\frac{L(1-\alpha)}{16\pi\sigma d^2}\right]^{1/4}.$$

- Gas with constituents of mass m will be lost in ~1 Gyr if

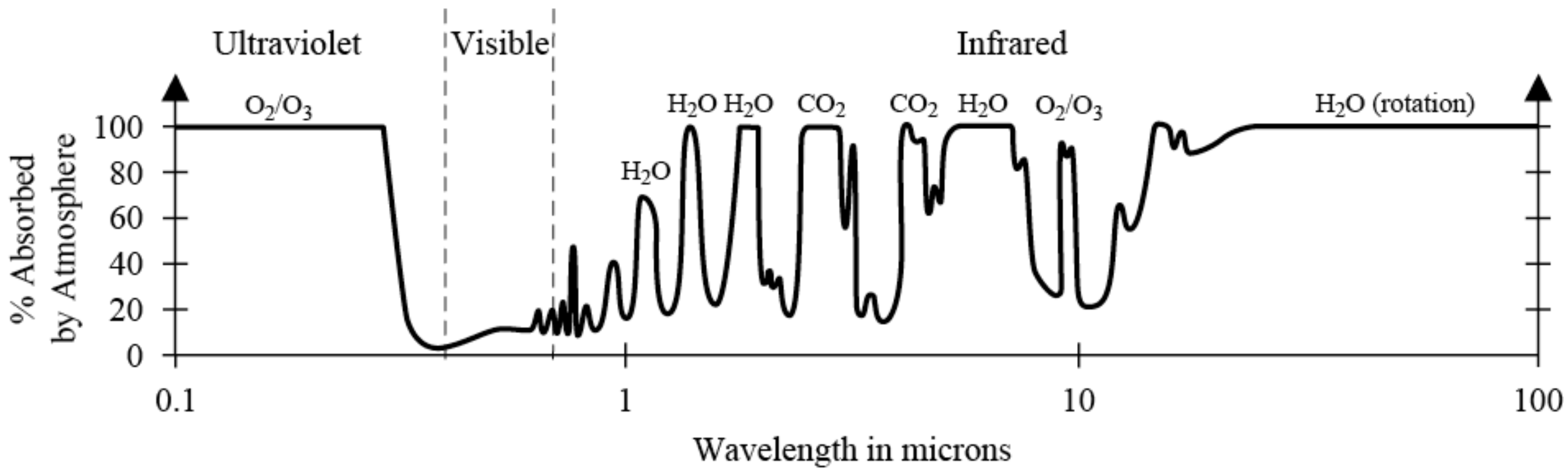
$$v_{\text{th}} \geq \frac{v_{\text{esc}}}{5} \text{ (approximately), where } v_{\text{esc}} = \sqrt{\frac{2GM}{R}} \text{ for the planet.}$$

Thermal Escape

Prob(v given T)~$v^2 \exp(-mv^2/2kT)$; remember, exp(x) means e^x

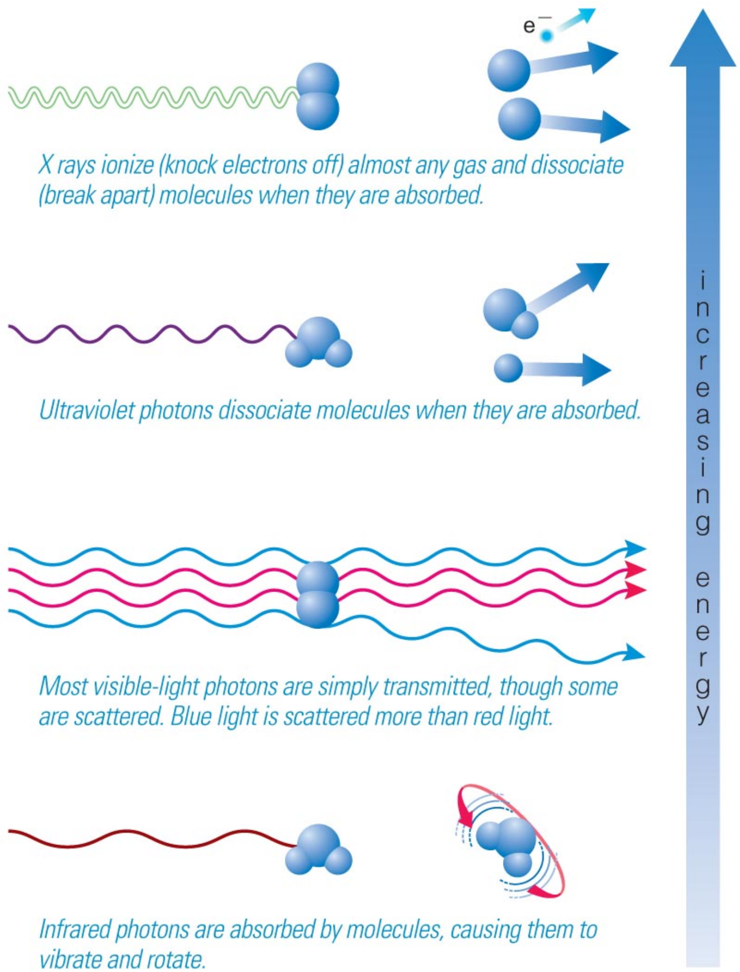


Atmospheric Absorption



- Recall, molecules in Earth's atmosphere absorb certain energies of light from the Sun and re-emit them in random directions.

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.

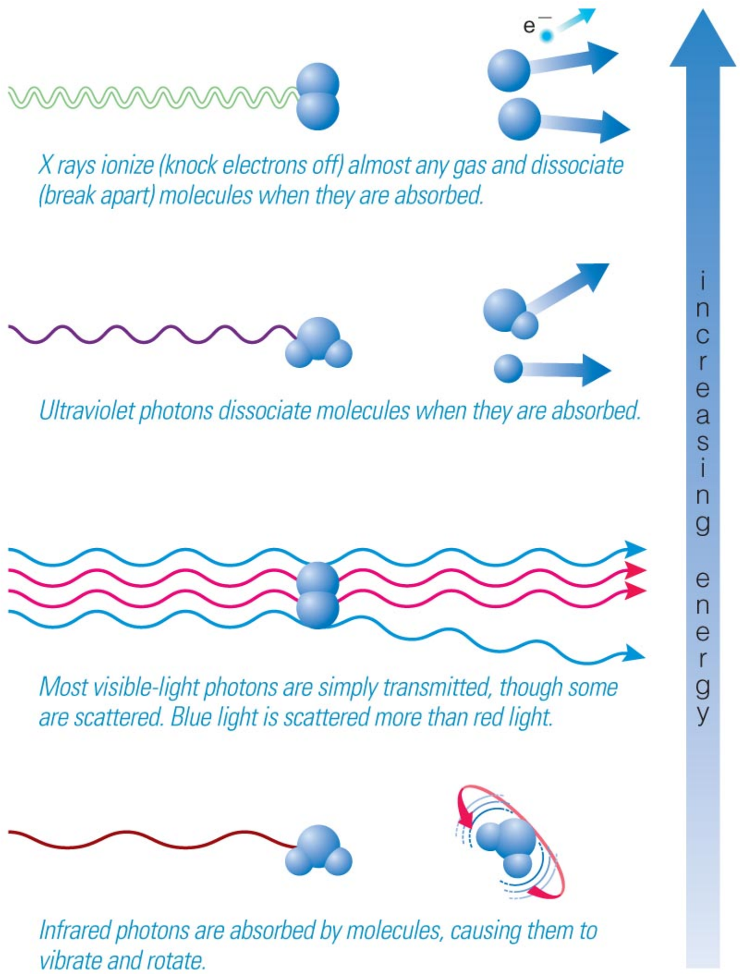
Why is the Sky Blue?

- And why are sunsets red?
- Same reason! Molecules scatter blue light much more easily than red light
- Thus away from the Sun, we get mainly blue light
- When the light goes through a lot of atmosphere (sunset), all blue has been scattered away
- Very important astronomical application; when we see a star through dust, it looks redder

  Then, want to use IR, not opt

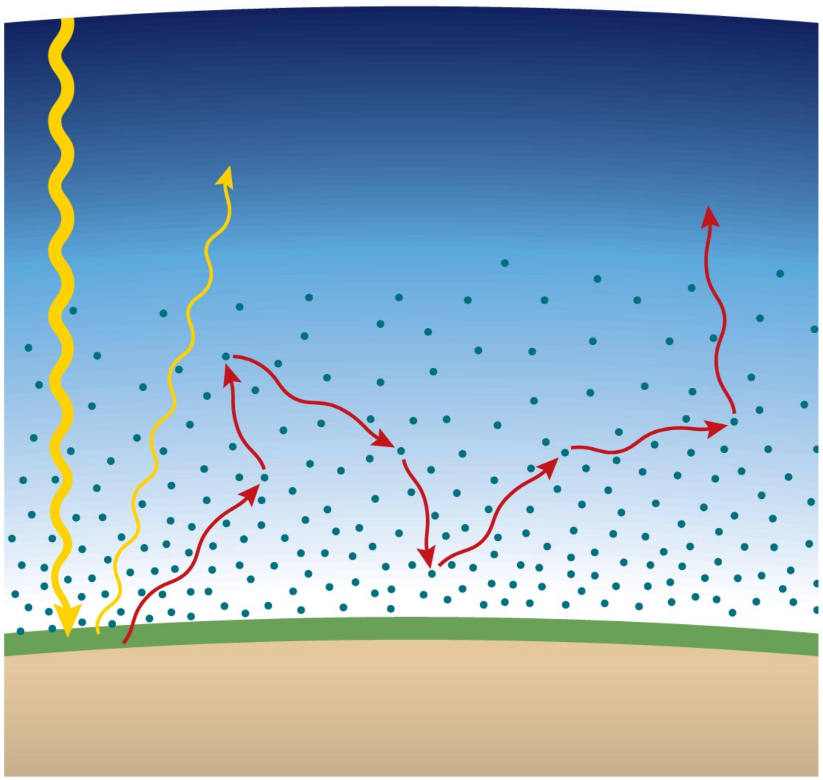
http://2.bp.blogspot.com/-SR7wwPTeLE4/TyG2wVZbZqI/AAAAAAAACog/EEoQB6ImNIc/s1600/beaches-blue-sky.jpeg

Light's Effects on Atmosphere



- X rays and UV light can ionize and dissociate molecules [heating].
- Air molecules scatter blue light more than red [color].
- Molecules can absorb infrared light [heating].

Greenhouse Effect



Strongest greenhouse gases:

1. Water vapor
2. Carbon dioxide
3. Methane

- Visible light passes through the atmosphere and warms a planet's surface.
- The warm surface emits infrared light (IR).
- Greenhouse gases absorb and re-emit IR, sending some back toward Earth's surface, making it hotter than it would be otherwise.

Atmospheric Temperature and the Greenhouse Effect

- Recall atmospheres transmit and absorb different wavelength ranges of light.
- Absorption causes heating.
  - ***Thermosphere***: X rays and UV ionize and dissociate gases.
  - ***Stratosphere***: On Earth, UV absorbed by O_2 and ozone (O_3).
  - ***Troposphere***: IR absorbed by molecules like H_2O, CO_2, CH_4.
- The ***greenhouse effect*** is caused by the atmosphere absorbing IR from the planetary surface and sending some of that energy back down to the surface.
  - Surface heated originally by incoming sunlight that is not reflected.
  - The surface is too cold to emit visible light, but it does emit IR.