Astronomy 210
Section 1– MWF 1500-1550
134 Astronomy Building

This Class (Lecture 17):

Planetary Temperatures

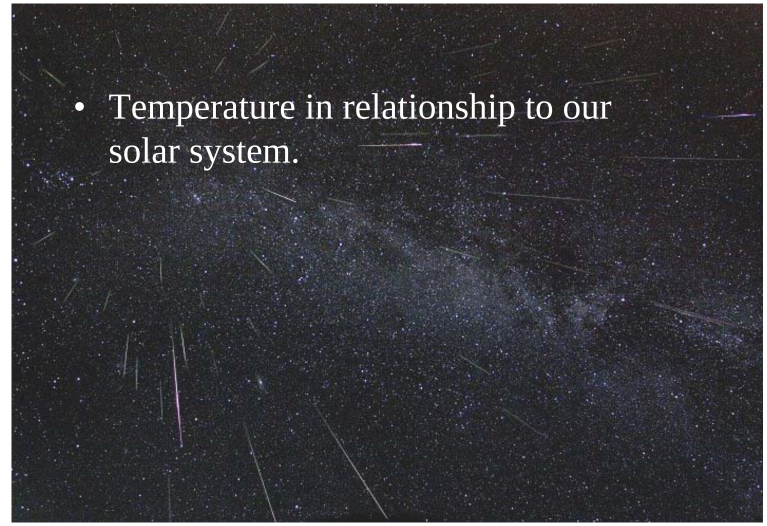
HW 5 due Friday

Night Observations

Next Class:

Planetary Atmospheres

Outline



- Temperature in relationship to our solar system.

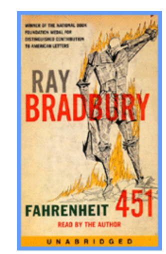
Temperature

- By measuring temperature, we are measuring the average kinetic energy of an object
  - Sort of the jiggling of the molecules. A high temperature ⇒ higher energy and faster
- Three commonly used temperature scales:
  - Fahrenheit
  - Celsius
  - Kelvin

But there are more.

Fahrenheit (1714)

- From Gabriel Daniel Fahrenheit (German physicist)
- First to use the metal mercury
- Zero was lowest temperature he could reach (freezing point of a mixture of ice and salt)
- Freezing point of water is 32 degrees F
- Water Boils at 212 degrees F
- Advantage: human scale



http://www.raybradbury.com/books/images/covers/fahrenheit.gif
http://www.portalmundos.com/mundometeorologia/clima/valores.htm

Celsius (1742)

- From Anders Celsius (Swiss astronomer)
- Zero was set to freezing point of water
- 100 degrees was set to the boiling point of water

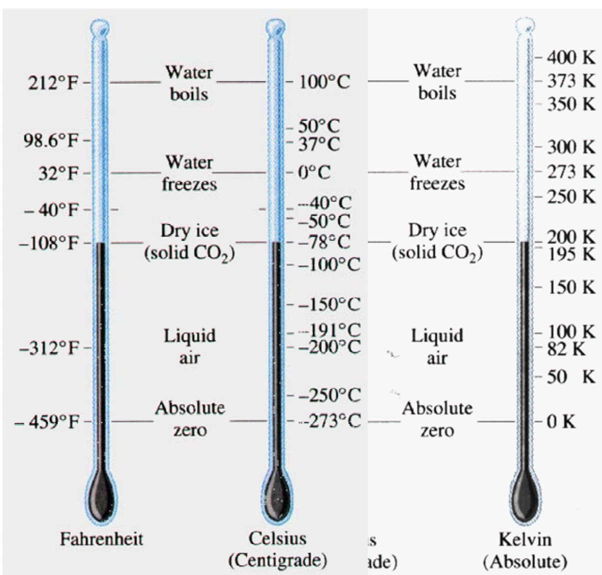
- Larger steps than Fahrenheit scale
- 1 F° = 5/9 C°

Kelvin (1848)

- From William Thomson Kelvin (UK Physicist)
- Set 0 K to absolute zero (where molecular energy is a minimum)
- Used same increment as Celsius scale (just add 273 degrees)
- Mostly widely used scale in science (makes equations simpler)

http://www.schoolscience.co.uk/content/5/physics/bama/aerosch2pg3.html

Temperature Scale Comparison



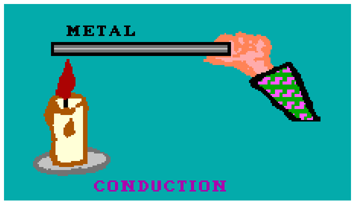
Heat Transport

- Heat passes from warmer to colder objects
- If there are several objects in contact, the warm ones become cooler and the cool ones become warmer
  - They tend to reach a common temperature
- This equalization of temperature happens in three ways:

Conduction, Convection, and Radiation

Heat Conduction

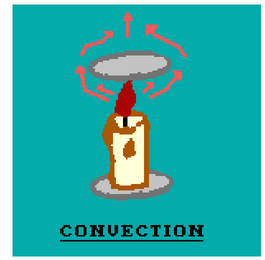
- Hold one end of a metal bar in a flame. It will quickly become too hot to hold.

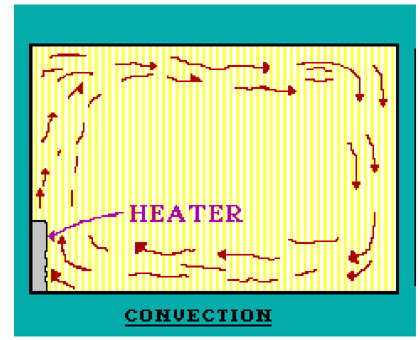


- Hold one end of a stick in a flame. You can have the stick catch fire and still you can hold the stick.

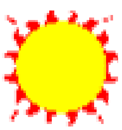
Heat Convection

- Main method for liquids and gases to transmit heat via flows or currents
- Examples:



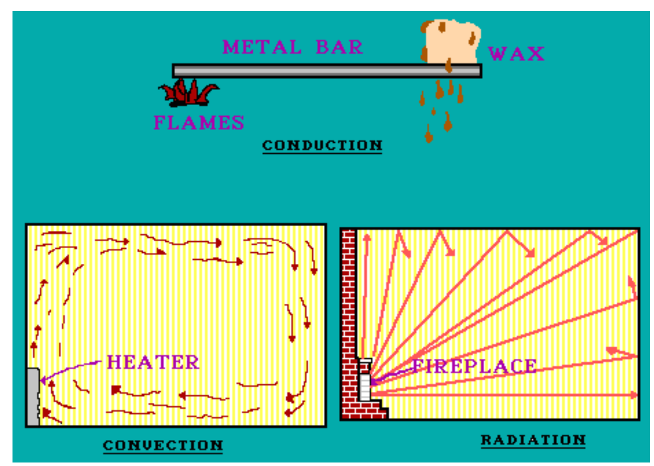


Heat Radiation



- How does the Sun's heat reach the earth?
  - There is vacuum between us so no conduction or convection
  - And the atmosphere is a poor conductor too
- It is emitting electro-magnetic waves, and especially infrared radiation. All matter releases radiant energy. Hotter matter releases more radiant energy than cooler matter.

Heat Transfer



Temperature

- Why would the planets have a temperature?
  - Equilibrium between absorption and emission.
  - How much energy is absorbed?

Sun has a luminosity L

energy/sec = energy

Recall

$$L_\odot = F_{surf} A_{surf} = \sigma T_\odot^4 4\pi R_\odot^2$$

So at planet

d

Temperature

- But not all of the light from the Sun is absorbed, or we couldn't see it in space.
  - Some light/energy is reflected

Define Albedo

$$A = \frac{\text{Amount of light reflected}}{\text{incident light}}$$

What is A for a blackbody?

A for a mirror?

Temperature

$$A = \frac{\text{Amount of light reflected}}{\text{incident light}}$$

So if A is the fraction reflected, then (1-A) is the fraction absorbed.

In that case, the absorbed flux is

$$F_{abs} = (1-A)\frac{L}{4\pi d^2}$$

Temperature

$$F_{abs} = (1-A)\frac{L}{4\pi d^2}$$

Then the energy absorbed by the planet

Temperature

- Emission from the absorbed energy. The emitted flux is σT^4
- But what temperature do I use? Avg Temp.
- But what area do I use?

  - Case I: Slowly rotating no atmosphere. Cool backside, and only dayside really emits.
  - Case II: Faster rotating, with atmosphere. All hemispheres are hot and emit.

    - Case I: $S_{emit} = 4\pi R^2/2 = 2\pi R^2$
    - Case II: $S_{emit} = 4\pi R^2$

Temperature

- Energy emitted per second is
  - $W_{emit} = S_{emit}\, T^4$
- In equilibrium:
  - $W_{abs} = W_{emit}$

$$\pi R^2 (1-A)\sigma T_\odot^4 (R_\odot / d)^2 = \begin{Bmatrix} 2\pi R^2 \\ 4\pi R^2 \end{Bmatrix} \sigma T^4$$

Temperature

- Planet temperature set by star temperature!
- Does not depend on the planet's radius!

Temperature

- For Earth, we use A = 0.37, d=1 AU, fast rotator, night side and day side are similar temperature.

$$T = 279\,K \left(\frac{1-0.37}{1^2}\right)^{1/4} = 248.6K$$

T = -24 C = -12 F

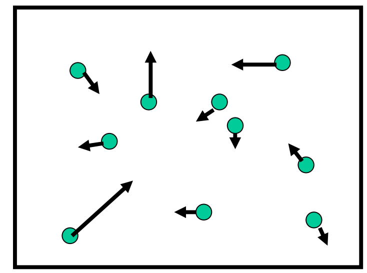
Okay, not a bad estimate. I didn't take into account the greenhouse effect, or the non-perfect blackbody modification. How would I do this for the Moon?

Planetary Atmospheres

- **Atmosphere:**
  - The gaseous envelope surrounding a planet (or satellite)
- Terrestrial planets
  - Mercury + Moon: no substantial atmosphere
  - Venus + Mars: CO_2 rich atmospheres
  - Earth: N_2 + O_2 atmosphere
- Jovian planets
  - Molecular H and He atmospheres
- Titan: N_2 atmosphere

Atmosphere Models

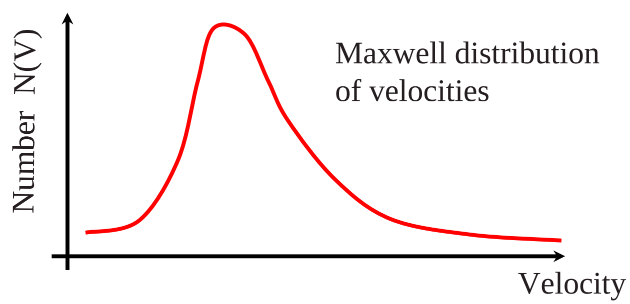
"Particles in a box" gas model
- Particles move in random directions
- Particles "collide" and exchange kinetic energy
- Some particles move rapidly, others more slowly
- All are following a distribution of velocities



⇐ length of arrow indicates speed of molecule

Distribution of Speeds

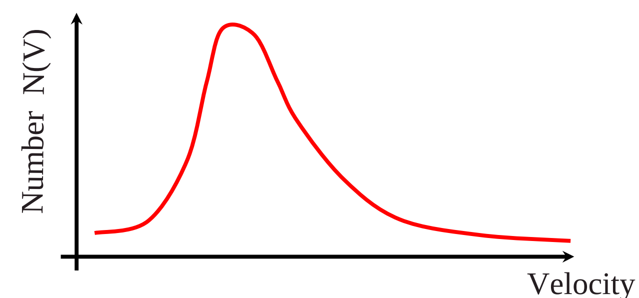
Looking at a large sample of particles produces a so-called Maxwell distribution of velocities.



What is the average velocity?

Distribution of Speeds

Average velocity is defined as $\langle \vec{v} \rangle$

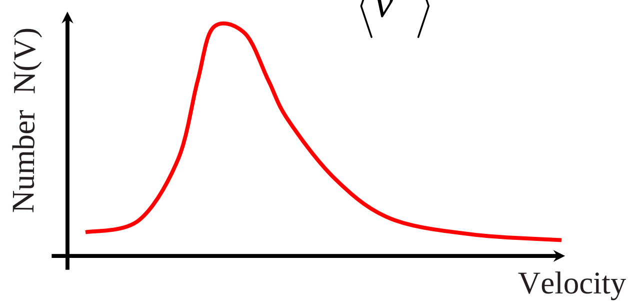


What is the average velocity?

Distribution of Speeds

But what about average of the squared velocity?

$$\langle \vec{v}^2 \rangle$$



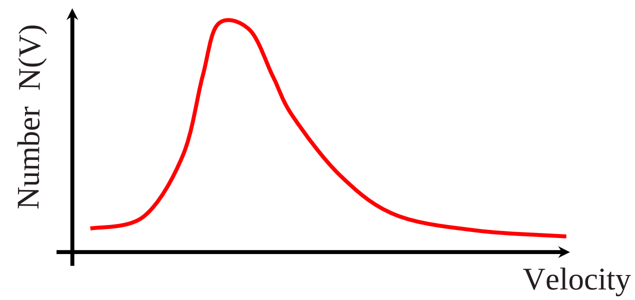
What is the average squared velocity?

Distribution of Speeds

Boltzmann derived

$$\langle KE \rangle = \tfrac{1}{2} m \langle \vec{v}^2 \rangle = \tfrac{3}{2} kT$$

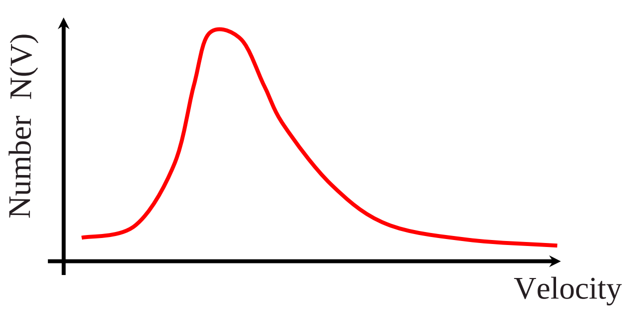
k is Boltzmann constant 1.38 x 10^{-23}J/K
m is the gas particle mass



Distribution of Speeds

Boltzmann derived

$$KE_{peak} = \tfrac{1}{2} m v_{peak}^2 = kT$$

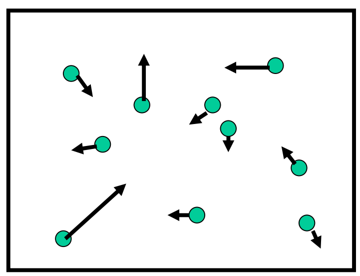


Temperature Results

- $v_{rms} \propto T$ $\Rightarrow$ the hotter, the faster on average
- $v_{rms} \propto 1/m$ $\Rightarrow$ the more massive, the slower on average
- In the classroom, the air is mostly N_2 (μ=28) and O_2 (μ=32), so Nitrogen is moving the fastest. How fast?
- At 300K (room temp), N is moving at an average velocity of 500 m/s!!! Or 1100 mph!
- Then what about smells?

Pressurized

Collisions with the walls of the box transfer momentum (change velocity) that implies a change in acceleration, which means a force. That force can be interpreted as pressure. For an ideal gas:



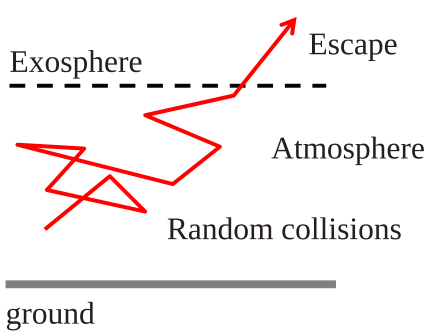
Planetary Atmospheres

- Terrestrial planets
  - No light gases (H_2 and He) only heavier N_2, O_2, CO_2
- Jovian planets
  - Mostly light gases (H_2 and He)

Why is there a difference?

Up, Up, and Away

- The atmosphere can escape!
- But what are the requirements?
- It is Gravity vs. Thermal Motion!



$$v_{rms} > v_{escape}$$

Analogy:
the atmosphere is
a gas in a leaky box

Do I go or do I stay?

- Test case: H gas on the Moon.

$$v_{escape} = \sqrt{2GM/R} = 2.4\times10^3 \text{m/s}$$

- The average thermal speed for H on the Moon is

$$v_{rms} = 2.6\times10^3 \text{ m/s}$$

- So $v_{rms} > v_{escape}$. Check, no H atmosphere on Moon!

Not the Whole Story

- Even if $v_{rms} < v_{escape}$, some particles will still escape.
- Recall the 'high-speed' tail of the Maxwellian distribution
- For an object to keep an atmosphere over the age of the Solar System (4.5 billion years), the escape condition is more like

$$v_{escape} \geq 10\ v_{rms}$$

- The factor of 10 accounts for the high-velocity tail of the maxewellian distribution of speeds.

This is a case of the tail wagging the dog

And?

Species	v_{escape}/v_{rms}	Lifetime
H on Moon	0.9	Hours
H on Earth	2.1	Days
Sodium on Moon	4	~10^3 years
O_2 on Earth	12	⇒∞: no escape

Earth's Atmosphere

- Atmosphere is essential to live, made from Nitrogen and Oxygen– rare in other planets atmosphere
- However, this is the Earth's 3rd atmosphere
  - First was hydrogen and helium
  - Second was from volcanoes– carbon dioxide and some nitrogen (more like Venus)
  - Water helped dissolve the CO_2, and we arrived at the atmosphere we have today (thanks to life)

Layers of the Atmosphere