Astronomy 210

Section 1– MWF 1500-1550
134 Astronomy Building

<u>This Class (Lecture 18):</u>

Planetary Atmospheres

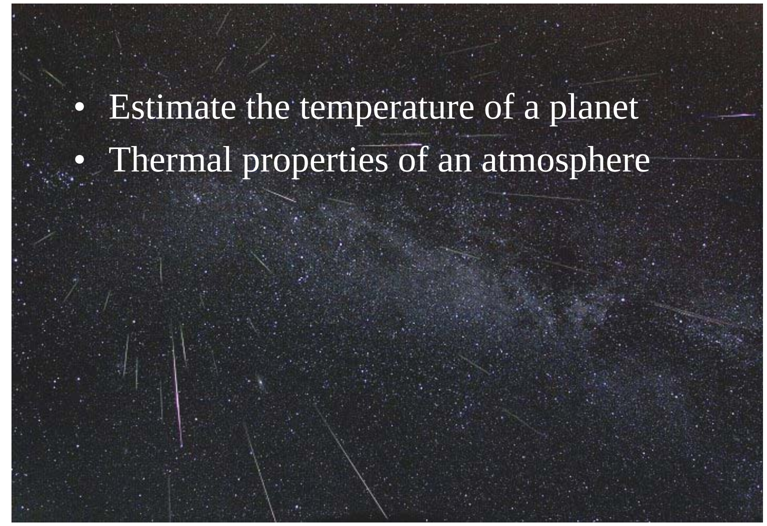
<u>Next Class:</u>

The Earth

HW 5 & Planetarium due Friday!

Night Observations!

Outline



- Estimate the temperature of a planet
- Thermal properties of an atmosphere

Temperature

- Energy emitted per second is
  - $W_{emit} = S_{emit}\,\sigma T^4$
- 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!

Where d is in AU!

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?

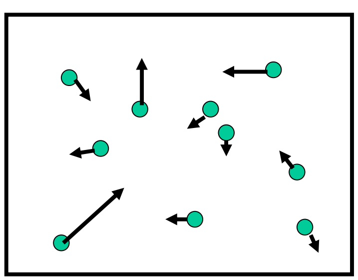
Planetary Atmospheres

- **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

<u>"Particles in a box" gas model</u>

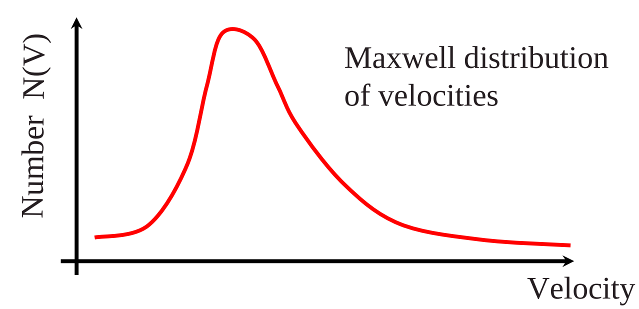
- Particles move in random directions
- Particles "collide" and exchange kinetic energy
- Some particles move rapidly, others more slowly
- All are following a distribution of velocities



⇐ length of arrow indicates speed of molecule

Distribution of Speeds

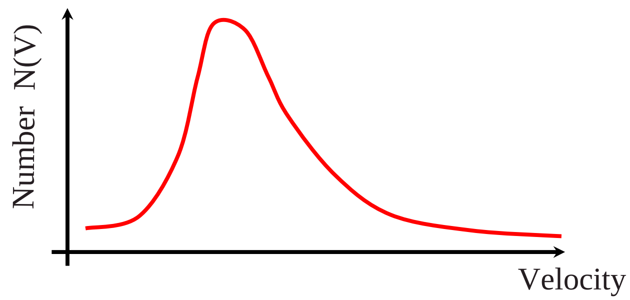
Looking at a large sample of particles produces a so-called Maxwell distribution of velocities.



What is the average velocity?

Distribution of Speeds

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

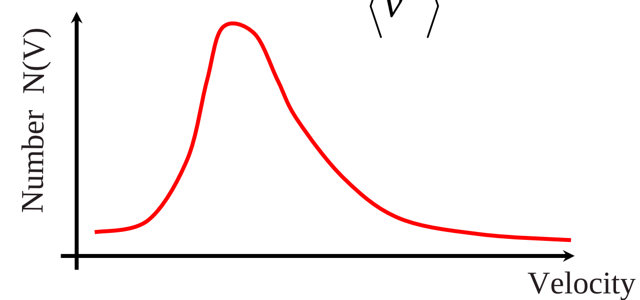


What is the average velocity?

Distribution of Speeds

But what about average of the squared velocity?

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



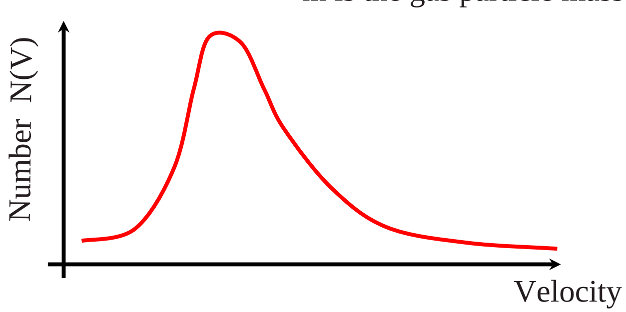
What is the average squared velocity?

Distribution of Speeds

Boltzmann derived

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

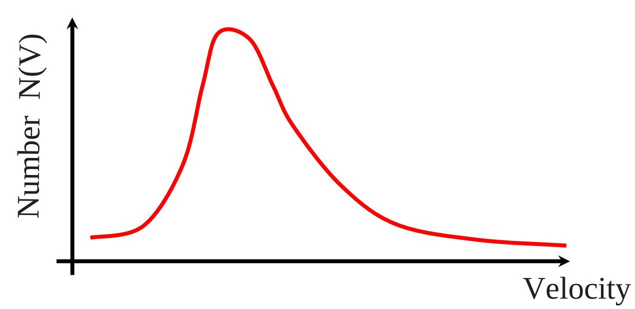
k is Boltzmann constant 1.38 x 10^{-23}J/K
m is the gas particle mass



Distribution of Speeds

Boltzmann derived

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



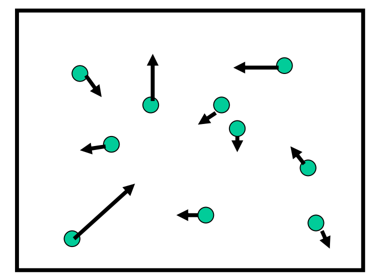
Temperature Results

- $v_{rms} \propto T$ $\Rightarrow$ 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:

$$PV = NkT$$



Planetary Atmospheres

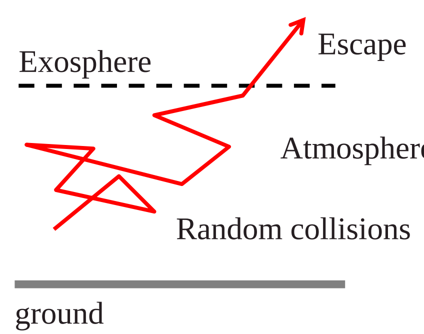
- Terrestrial planets
  - No light gases (H_2 and He) only heavier N_2, O_2, CO_2
- Jovian planets
  - Mostly light gases (H_2 and He)

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.

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

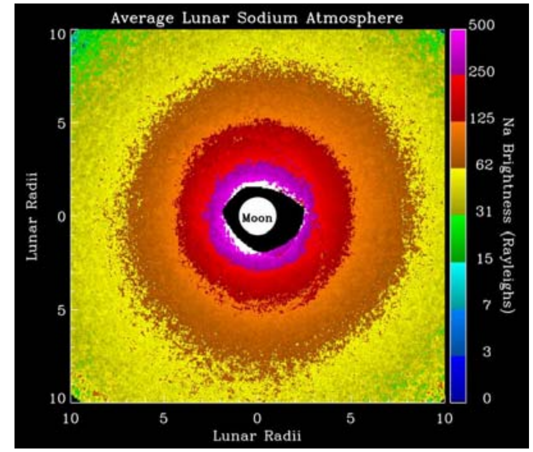
- The average thermal speed for H on the Moon is

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

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

Moon Atmosphere

- The Moon has a tenuous sodium atmosphere, that it is constantly losing and replenishing.
- Sort of like a comet in some ways.



http://sirius.bu.edu/planetary/moon.html

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

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

This is a case of the tail wagging the dog

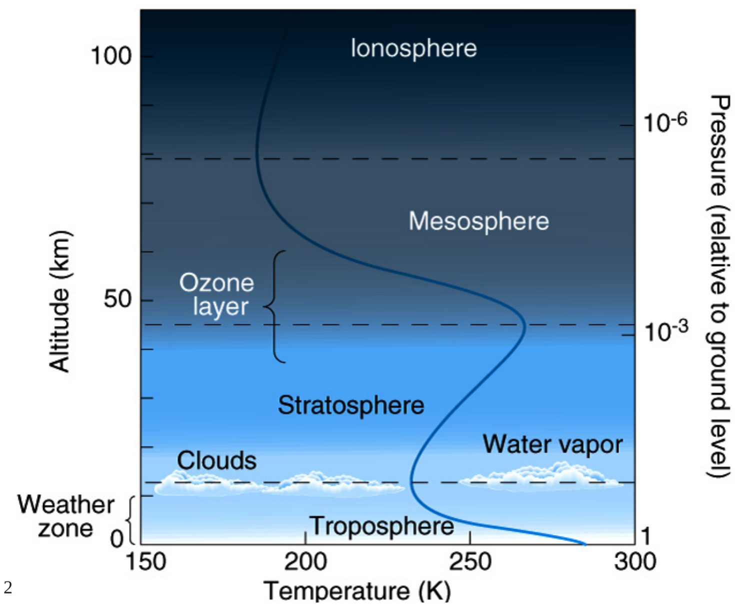
And?

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	$\Rightarrow\infty$: 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



The Solar System is Ours!