Astronomy 210

Section 1– MWF 1500-1550
134 Astronomy Building

This Class (Lecture 12):

Matter and Light

Next Class:

Thermal Radiation

Planetarium Observing

Exam #1 on Friday!

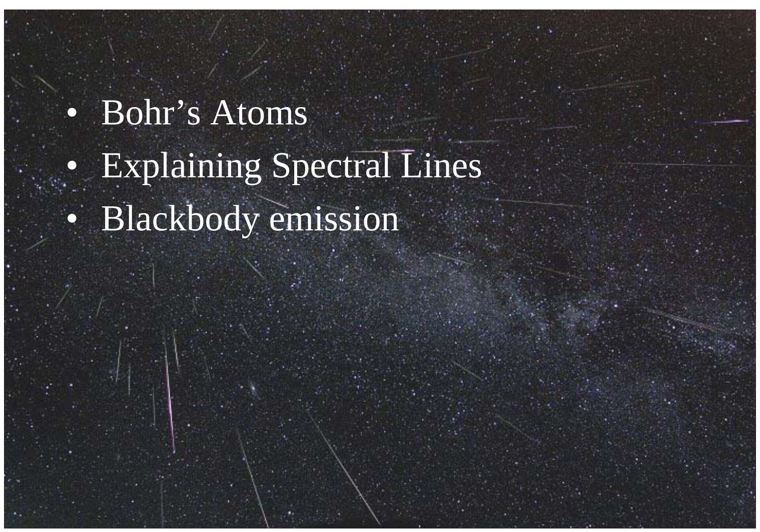
Thursday Review Session

Music: *Amy Hit the Atmosphere* – Counting Crows

Midterm #1

- 1 hour exam in this classroom.
- It will cover material up to, but not including, Blackbody emission
- Will consist of a few short-answers, 1-2 short essay, and a few problems + extra credit.
- You can bring a normal-sized sheet of paper with notes on both sides.

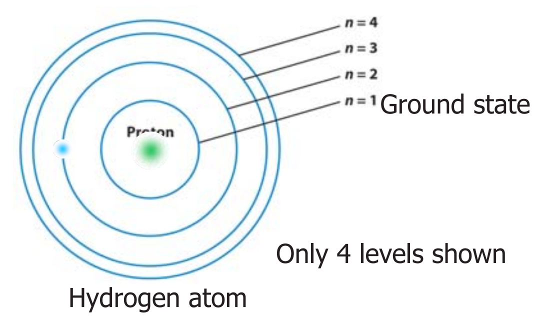
Outline



- Bohr's Atoms
- Explaining Spectral Lines
- Blackbody emission

Atomic Structure

- Electrons orbit the *nucleus* of each atom
- The nucleus consists of protons and neutrons
- Number of protons = number of electrons (total charge=0)
- The electrons can only have special orbits called *energy levels*
- The lowest energy level is the *ground state*



Explaining

Electron becomes a standing wave. Since the orbit is defined, only certain values allowed, such that

$$2\pi r = n\lambda = n\frac{h}{m_e v}$$

Orbit

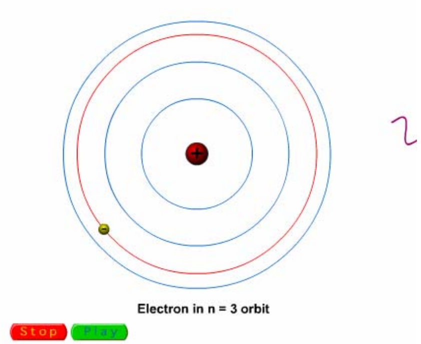
- So, if the electron is in an orbit, what is the force?
- Coulomb force provides centripetal acceleration. Like gravity, but different.

$$E_n = \frac{1}{2}m_2 v_n^2 - \frac{e^2}{r_n}$$

$$= -\frac{1}{n^2}\frac{e^4 m_e}{2\hbar^2} \propto \frac{1}{n^2}$$

How Do Spectrum Lines Form?

- Spectrum lines correspond to electron transitions between energy levels in an atom
- **Absorption:** light energy absorbed by atom, electron jumps to a higher energy level
- **Emission:** electron drops down to lower energy level; releases energy as light



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Changes in Levels

- For a transition, the photon emitted or absorbed is from the difference in level
- If electron goes from $n_a \Rightarrow n_b$ with $n_a > n_b$ then photon energy will be

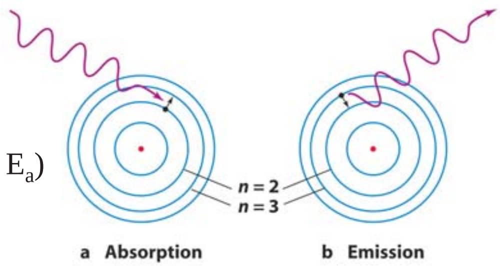
$$E_\gamma = E_{n_a} - E_{n_b}$$

$$= -\frac{e^4 m_e}{2\hbar^2}\left(\frac{1}{n_a^2} - \frac{1}{n_b^2}\right)$$

$$= -\frac{e^4 m_e}{2\hbar^2}\frac{n_a^2 - n_b^2}{n_a^2 n_b^2}$$

How Do Spectrum Lines Form?

- Spectral lines correspond to electron transitions between energy levels in an atom
- **Excitation:** electron jumps to a higher energy level ($E_b > E_a$)
  - Collision
  - γ absorption
- **Emission:** electron drops down to lower energy level; releases energy ($E_b < E_a$)
  - Collision
  - Spontaneous



Lambda, Lambda, Lambda

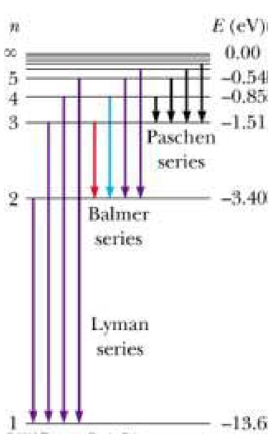
$$\lambda_\gamma = \frac{hc}{E_\gamma} \quad \text{can define } R = \frac{4\pi c\hbar^3}{e^4 m_e} = 1.1\times 10^7\, m^{-1}$$

Rydberg constant

$$\lambda_\gamma = \frac{1}{R}\frac{n_a^2 n_b^2}{n_a^2 - n_b^2}$$

With n_b=2, we obtain the Balmer result!

Series



new unit: 1 eV = 1.602 x 10^{-19} J

Or the amount of energy gained by an electron after going through a potential of 1 Volt.

n_b=1 $\Rightarrow$ Lyman series

n_b=2 $\Rightarrow$ Balmer series

n_b=3 $\Rightarrow$ Paschen series

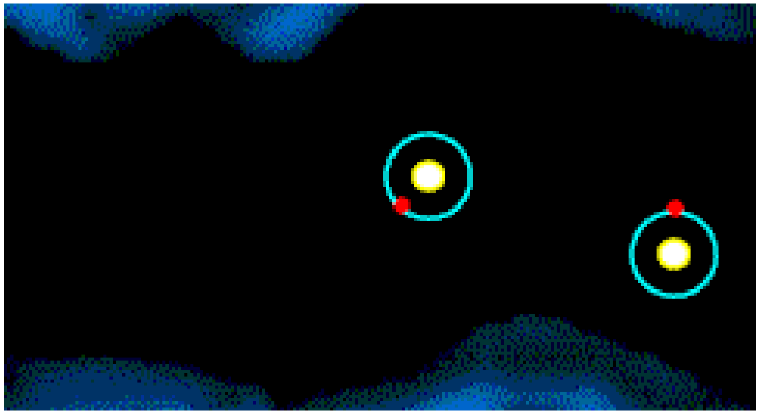
Ionize the Atom

- All E_n are bound states, E < 0 negative energies
- Also there are unbound states, E > 0, where the e^- is freed $\Rightarrow$ ionized!
- What is min E to ionize H from ground state (n = 1)?

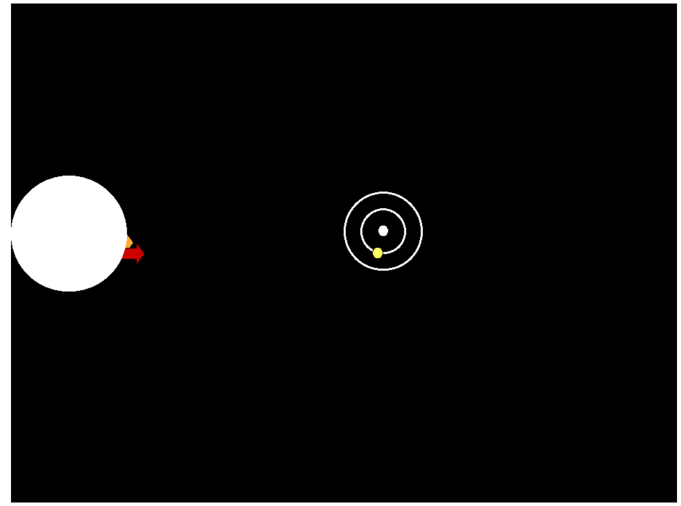
$$E_{ionize} = E_1 - E_\infty$$

Atom Collisions

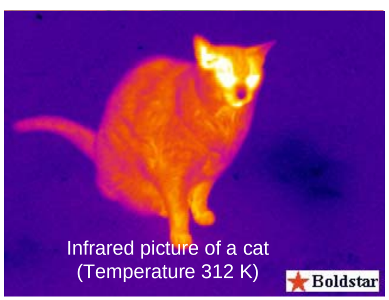
- Electrons get knocked-up to higher energy levels by collisions



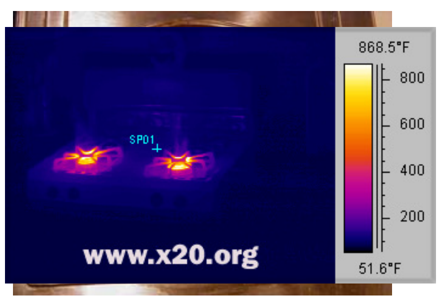
Creation of Absorption and Emission Line Spectra



Blackbody Radiation



Infrared picture of a cat
(Temperature 312 K)



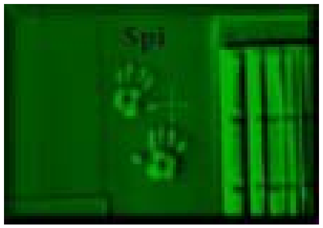
Visible-light picture of a stove element
(Temperature ~ 400 K)

Define Blackbody

- A perfect absorber of light
- It re-emits radiation according to its temperature
- Therefore, “blackbody radiation" = thermal radiation
- Usually, most familiar objects are well approximated as blackbody radiators
- The spectrum of this ideal, only depends on its temperature!
- A clear exception is a laser pointer.
  - Why?

Glowing Bodies

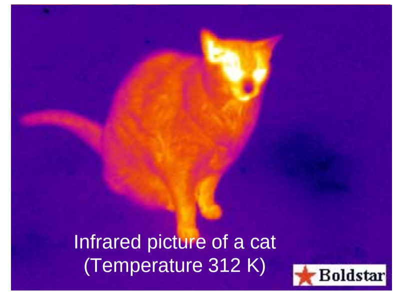
- So, everything we know is in fact giving off light– as long as it has a temperature, *it is glowing*.
- The higher the temperature the shorter the wavelength it glows in– compare the person on the right (in the near infrared) and a light bulb (in the visible).



http://www.x20.org/thermal/thermal_weapon_sight_TIWS320.htm

Blackbody Radiation

- Light that objects emit because of their temperature is called **blackbody radiation**
- Blackbody radiation is composed of a continuous spectrum of wavelengths
- The **hotter** an object gets, the **more intense** and **shorter wavelength** (blue-er) its blackbody radiation becomes

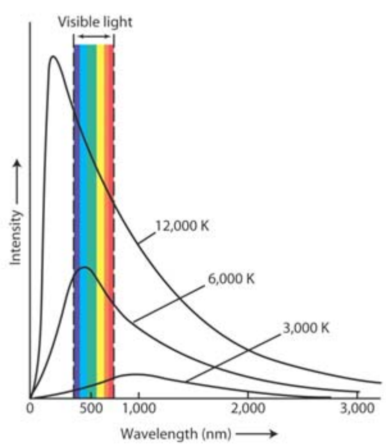


Infrared picture of a cat (Temperature 312 K)

Visible-light picture of a stove element (Temperature ~ 400 K)

The Spectrum of Blackbody Radiation

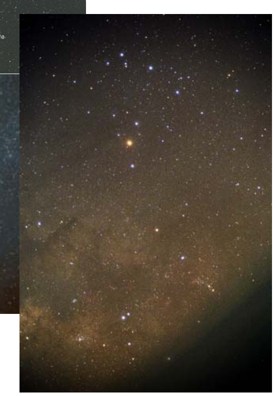
- Flux is > 0 for all λ
- The higher the temperature, the higher the flux for all λ
  (curves do not intersect!)
- For higher temperature the maximum occurs at shorter wavelengths.



Think-Pair-Share

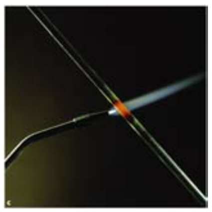
Which star is hotter?

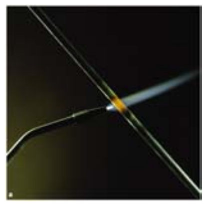
- Vega (blue)
- Capella (yellow)
- Antares (red)

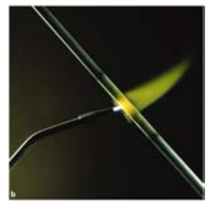


Red Hot?

- Actually Red hot is not too hot.
- Blue hot is hot.
- White hot is even hotter.







The Spectrum of Blackbody Radiation

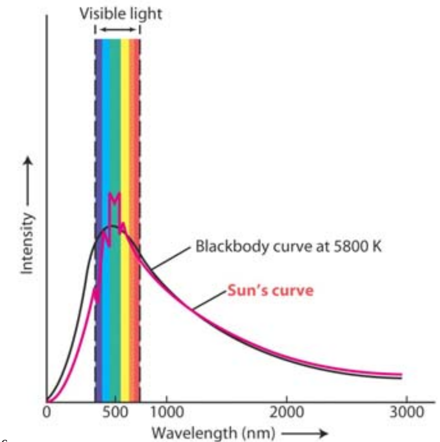
Sun's maximum is at $\cong 500$ nm

$$\text{So, } T \approx \frac{2.9\times10^{-3}\ \text{m K}}{500\times10^{-9}\ \text{m}} = 5800\ \text{K}$$

The Sun's spectrum looks almost like a 5800 K blackbody.

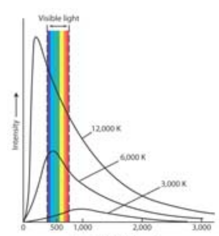
This is a very powerful tool! We can find the temperature by the spectrum.

Color ⇔ Temperature!



Blackbody Flux-ed

- The total flux from a blackbody is adding up the flux in the spectrum.
- Do you think it depends on temperature?



- Strongly dependent on temperature.
  - $F = \sigma T^4$ energy per per unit area per unit time

$$\sigma = 5.67\times10^{-8}\ \frac{\text{W}}{\text{m}^{-2}K^{-4}}\ \text{Stefan-Boltzmann}$$

Stephan-Boltzmann Law

- Example 1: If a star was the same size as the Sun, but was twice as hot, it would be **16 times** as bright.
- Example 2: The total rate of energy emission from Sun = total solar power output = solar luminosity

$$L_{\odot} = 3.85\times10^{26} W$$

$$F = \frac{L}{Surf.Area} = \frac{L}{4\pi R_{\odot}^2}$$

$$= \frac{3.85\times10^{26} W}{4\pi(7.0\times10^{8} m)^2} = 6.3\times10^{7}\ \frac{W}{m^2}$$

$$T^4 = \frac{F}{\sigma}$$

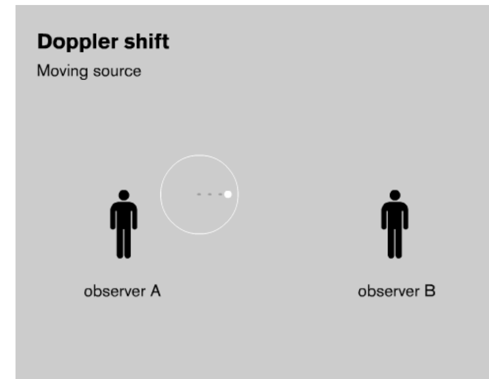
$$T = \left(\frac{F}{\sigma}\right)^{\frac{1}{4}} = 5800K$$

Doppler Effect

Those of you use to racing events like the Indy 500, or the sound of a police siren, are use to the Doppler effect.

Velocity and the Doppler Effect

- The effect arises from the relative motion between a source of light, sound, etc…, and an observer
- Waves get squashed in the direction of motion
  - For light waves, called **blueshift**
- Waves are stretched in the opposite direction
  - For light waves, called **redshift**



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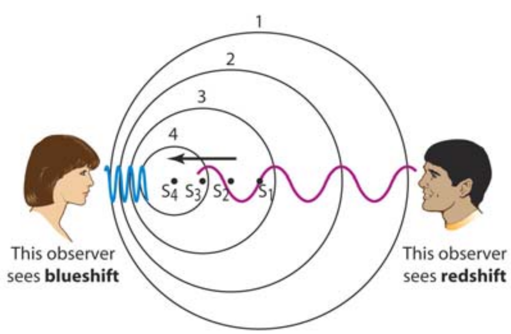
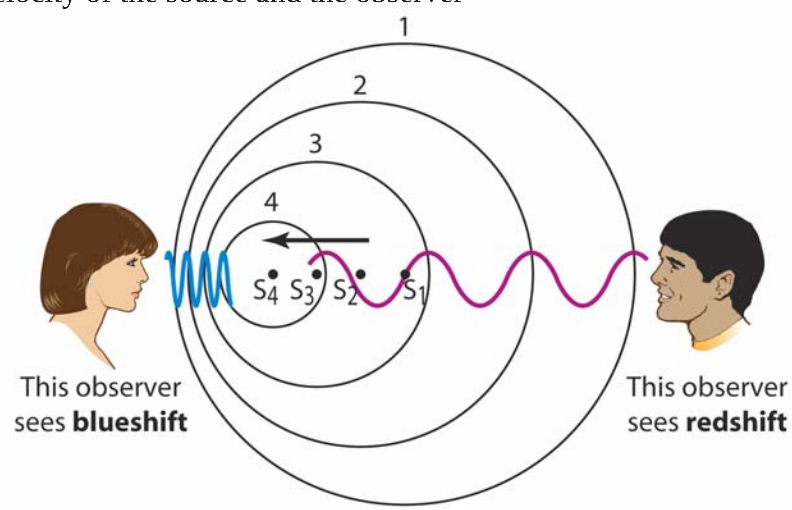


The Doppler Effect

The amount of the shift in wavelength depends on the relative velocity of the source and the observer



Doppler Shift

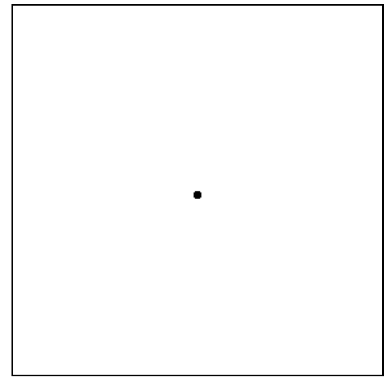
- The amount of shift in wavelength depends on the *relative* velocity of the source and the observer

$$\lambda_{obs} - \lambda_{source} = \lambda_{source} \times \left(\frac{v_{source}}{c} \right)$$

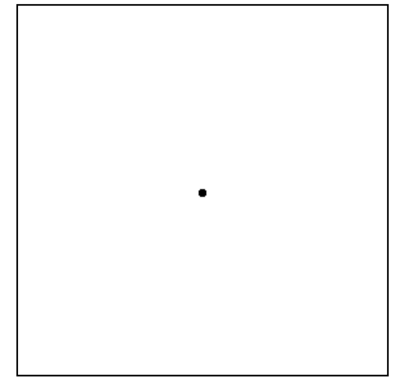
- By measuring the Doppler shift of the light we observe, we can study the motions of the planets and stars
- The Doppler effect is also used by modern storm-tracking radar

The Doppler Effect

The effect arises from the relative motion of the observer and the source of light, sound, etc. The waves get squashed in the direction of motion and stretched in the opposite direction.



Source standing still



Source moving to right

Question

- We measure the Hα line (the first line in the Balmer series) in a star forming region.
- The emission line is measured at 656.7nm.
- On Earth the line is measured at 656.3nm.
- Is the emission red/blue shifted?
- How fast is the region moving relative to us?
- What would happen if an object were moving very fast? How could we tell which line was which?