

Astronomy 210

Section 1 – MWF 1500-1550

134 Astronomy Building

This Class (Lecture 11):

Spectroscopy

Planetarium Observing

Stardial Observing

Exam #1 next week

Next Class:

Matter and Light

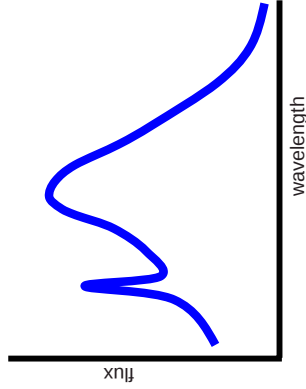
Music: *Space Dog* – Tori Amos

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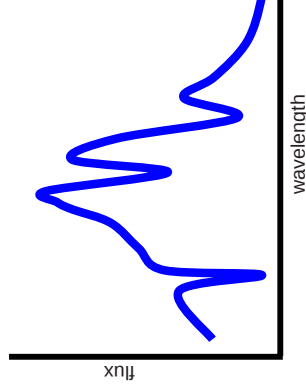
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The Spectrum

The “spectrum” of a light source also refers to the fractional contribution of all of the different wavelengths to its total light output. It is the Flux distribution vs λ .



Emission



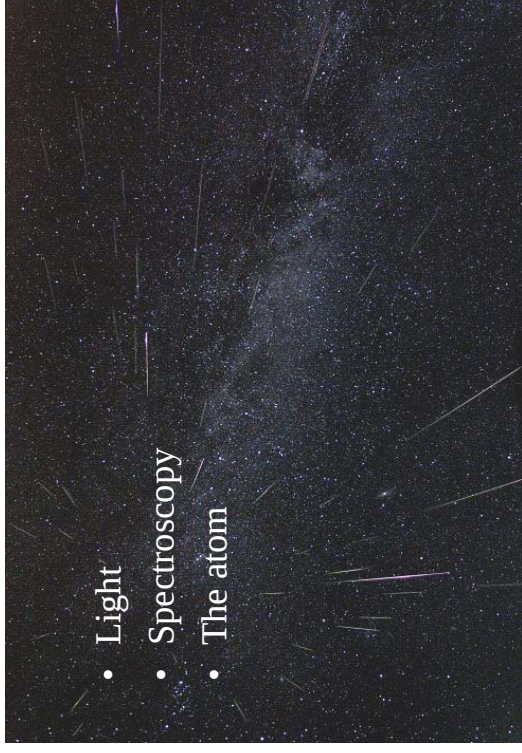
Absorption

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Outline

- Light
- Spectroscopy
- The atom

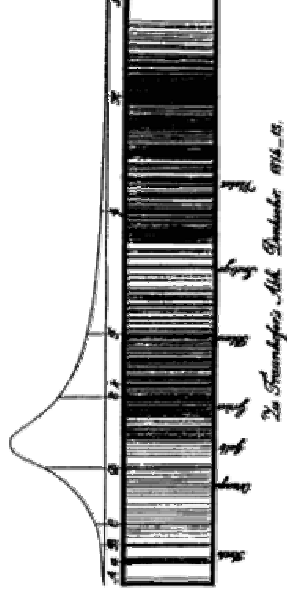


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Spectrum Lines

- Fraunhofer discovered that Sun’s spectrum contained narrow gaps (absorption lines) when viewed at high resolution (1814)



Joseph von Fraunhofer
(1787-1826)

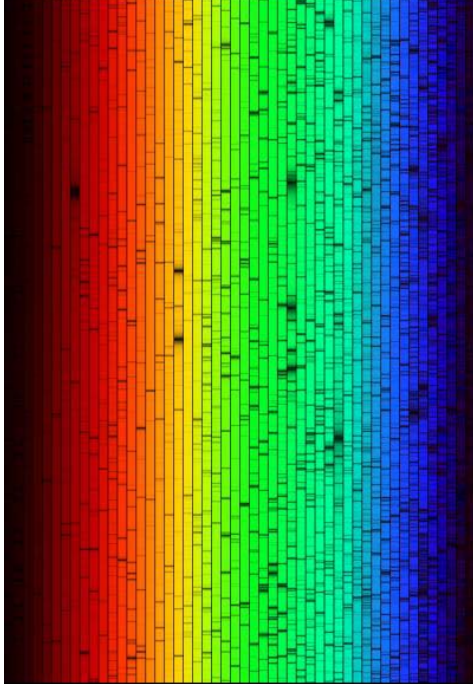


Prism spectrograph

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What Color is Sunlight?

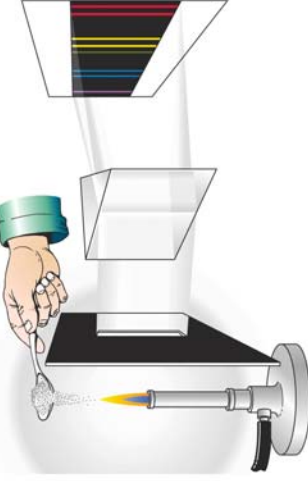


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<http://antwrp.gsfc.nasa.gov/apod/ap000815.html>

In the Laboratory

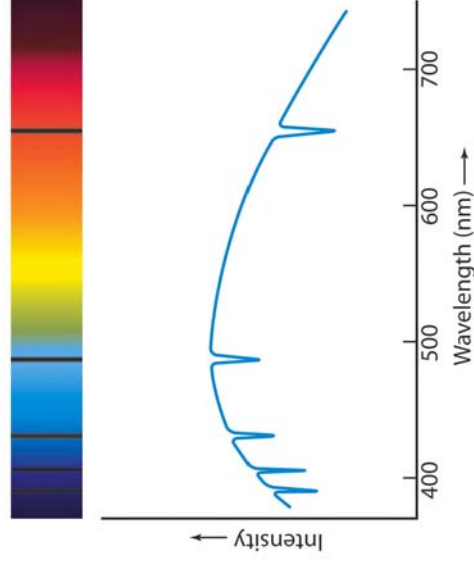


- Bright spectrum lines were produced and studied in the laboratory in the mid-1800s
- Discovered that burning different chemical elements produced different patterns of lines

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Spectrum Lines



- When astronomers looked at the spectra of the Sun and stars, they saw **gaps**
- Not a perfect smooth spectrum!
- Called *dark spectrum lines*

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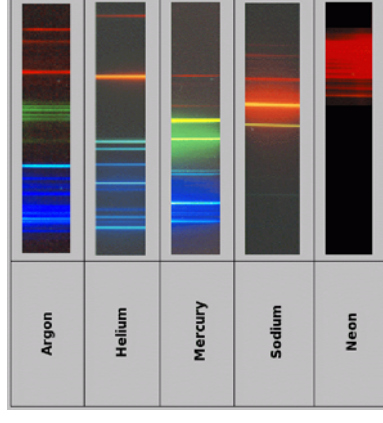
Spectrum Lines = Fingerprints



The pattern of spectrum lines produced by a gas depends on its chemical composition



Or a barcode!



<http://www.astru.washington.edu/astro101v>

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Kirchoff's Laws

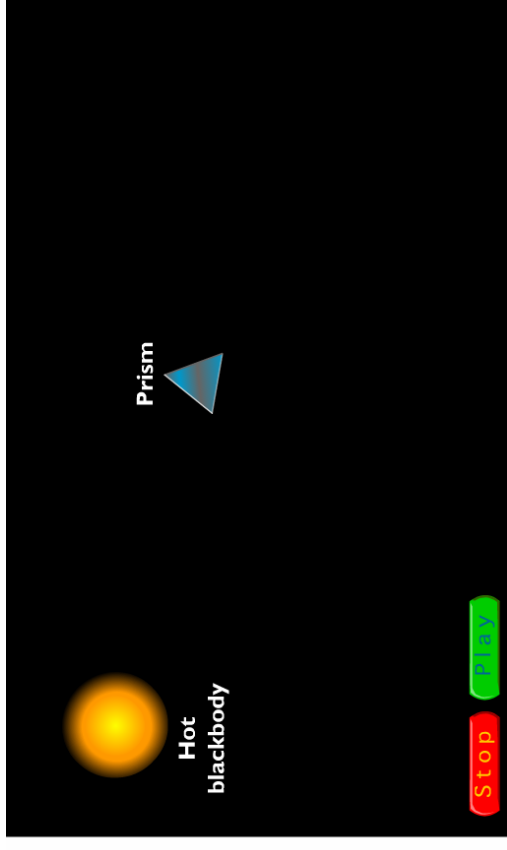


- In 1859, Gustav Kirchhoff discovered the conditions under which three basic types of spectra are formed:
 - A hot, dense object produces a **continuous spectrum**
 - A hot low-density gas produces an **emission-line spectrum**
 - A continuous spectrum source viewed through a cooler gas produces an **absorption-line spectrum**

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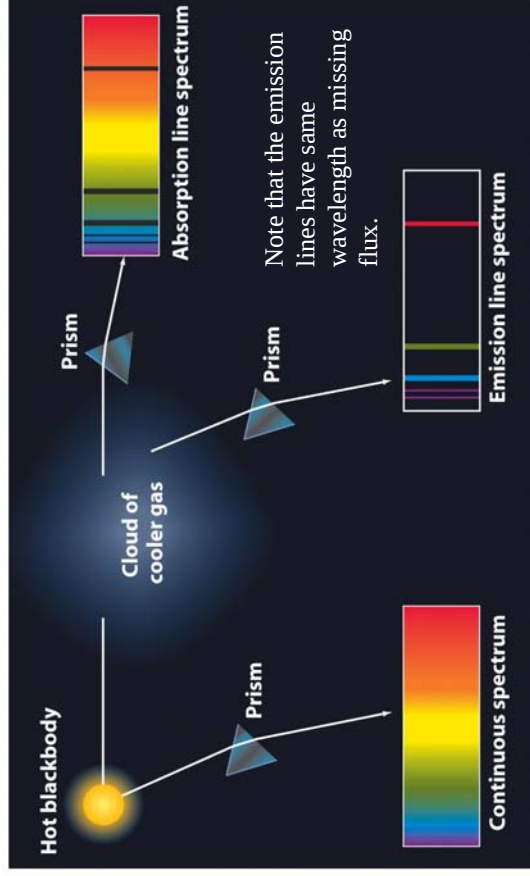
Kirchoff's Laws



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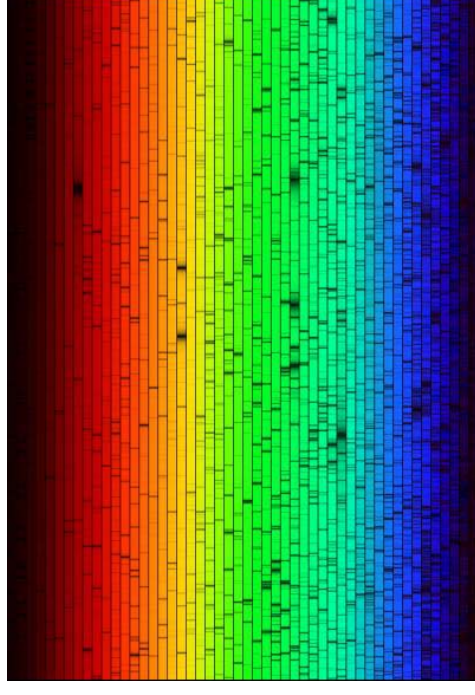
Kirchoff's Laws



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What Color is Sunlight?



Sun is a hot, dense object
So, there must be a cooler, less dense solar atmosphere surrounding it.

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<http://anwrp.gsfc.nasa.gov/apod/ap000815.html>

How Do Spectrum Lines Form?



To answer this question, we need to delve into the structure of matter itself...

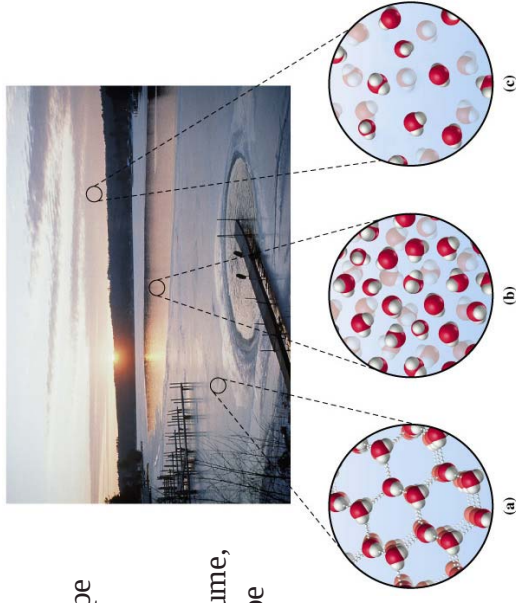
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States of Matter



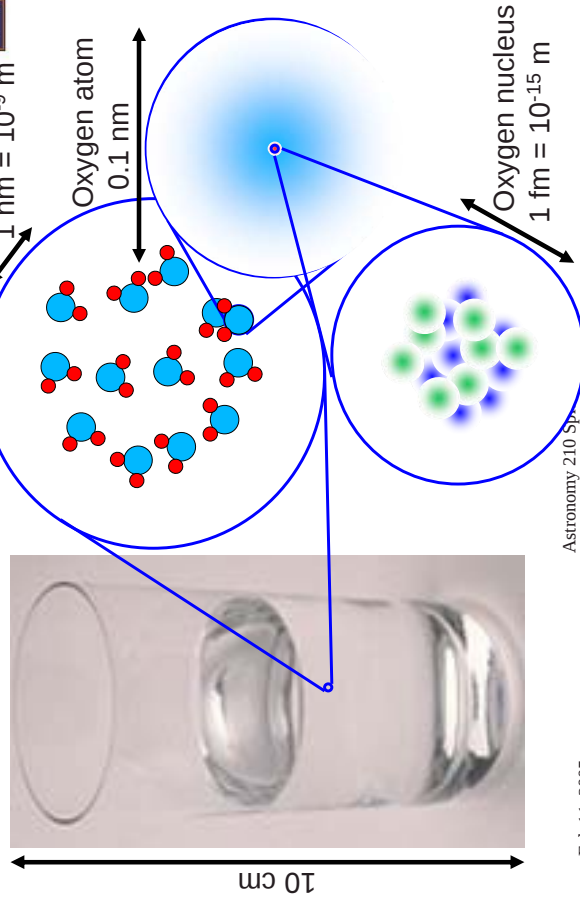
- Solid
 - Definite shape and volume
- Liquid
 - Definite volume, flexible shape
- Gas
 - Flexible shape *and* volume



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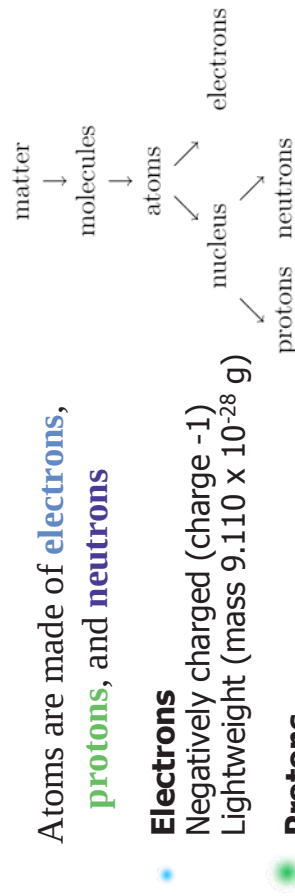
A Glass of Water



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Parts of an Atom



Atoms are made of **electrons**, **protons**, and **neutrons**

Electrons

Negatively charged (charge -1)
Lightweight (mass 9.110×10^{-28} g)

Protons

Positively charged (charge +1)
1832 times as massive as an electron (mass 1.673×10^{-24} g)

Neutrons

No electric charge
A little more massive than a proton (mass 1.675×10^{-24} g)

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Atoms and Elements



- All matter is made of **elements**
 - 92 natural and 23+ artificial
 - Hydrogen, Carbon, Oxygen, Iron, Uranium, etc.
 - Each element is composed of a different kind of **atom**
- The number of protons (or Z) in an atom determines the type of element
 - Hydrogen has 1 proton (Z=1), oxygen has 8 protons (Z=8), etc.
- Neutrons are “packing material” .
- Atoms interact via electrons
 - Shared among atoms to make **molecules**
 - Atoms missing or with extra electrons are called **ions**

Isotopes



- Same element (same # p) can have different # neutrons.
 - ⇒ isotopes
- For example, most H is $^1\text{H} = 1\text{p}, 0\text{n}$
- but $\sim 10^{-4}$ of H is deuterium $^2\text{H} = 1\text{p}, 1\text{n}$
- About 10 kg of your body is ^1H , and 1g is deuterium
- Or most U is $^{238}\text{U} = 92\text{p}, 146\text{n}$



<http://www.stetbigade.com/SDpromotions.html>

Periodic Table



1	H	Hydrogen	2	He	Helium
3	Li	Lithium	4	Be	Beryllium
5	B	Boron	6	C	Carbon
7	N	Nitrogen	8	O	Oxygen
9	F	Fluorine	10	Ne	Neon
11	Na	Sodium	12	Mg	Magnesium
13	Al	Aluminum	14	Si	Silicon
15	P	Phosphorus	16	S	Sulfur
17	Cl	Chlorine	18	Ar	Argon
19	K	Potassium	20	Ca	Calcium
21	Sc	Scandium	22	Ti	Titanium
23	V	Vanadium	24	Cr	Chromium
25	Mn	Manganese	26	Fe	Iron
27	Co	Cobalt	28	Ni	Nickel
29	Cu	Copper	30	Zn	Zinc
31	Ga	Gallium	32	Ge	Germanium
33	As	Arsenic	34	Se	Selenium
35	Br	Bromine	36	Kr	Krypton
37	Rb	Rubidium	38	Sr	Strontium
39	Y	Yttrium	40	Zr	Zirconium
41	Nb	Niobium	42	Mo	Molybdenum
43	Tc	Technetium	44	Ru	Ruthenium
45	Rh	Rhodium	46	Pd	Palladium
47	Ag	Silver	48	Cd	Cadmium
49	In	Indium	50	Sn	Tin
51	Sb	Antimony	52	Te	Tellurium
53	I	Iodine	54	Xe	Xenon
55	Cs	Cesium	56	Ba	Barium
57	La	Lanthanum	58	Ce	Cerium
59	Pr	Praseodymium	60	Nd	Neodymium
61	Pm	Promethium	62	Sm	Samarium
63	Eu	Europium	64	Gd	Gadolinium
65	Tb	Terbium	66	Dy	Dysprosium
67	Ho	Holmium	68	Er	Erbium
69	Tm	Thulium	70	Yb	Ytterbium
71	Lu	Lutetium	72	Hf	Hafnium
73	Ta	Tantalum	74	W	Tungsten
75	Re	Rhenium	76	Os	Osmium
77	Ir	Iridium	78	Pt	Platinum
79	Au	Gold	80	Hg	Mercury
81	Tl	Thallium	82	Pb	Lead
83	Bi	Bismuth	84	Po	Polonium
85	At	Astatine	86	Rn	Radon
87	Fr	Francium	88	Ra	Radium
89	Ac	Actinium	90	Th	Thorium
91	Pa	Protactinium	92	U	Uranium
93	Np	Neptunium	94	Pu	Plutonium
95	Am	Americium	96	Cm	Curium
97	Bk	Berkelium	98	Cf	Californium
99	Es	Einsteinium	100	Fm	Fermium
101	Md	Mendelevium	102	No	Nobelium
103	Lr	Lavenderium	104	Rf	Rutherfordium
105	Db	Dubnium	106	Sg	Seaborgium
107	Bh	Bohrium	108	Hs	Hassium
109	Mt	Moscovium	110		
111			112		
113			114		
115			116		
117			118		

Balmer



- Empirically found wavelengths of H emission lines

$$\lambda = 3.65 \times 10^{-7} \frac{n^2}{n^2 - 4} \text{ for } n \text{ integer } \geq 3$$

for n = 3

$$\lambda = 3.65 \times 10^{-7} \frac{9}{9 - 4} = 656 \text{ nm}$$

- What does this tell us?

Prince Louis-Victor de Broglie



- Not only does light behaves like particle & wave, but so does matter!
⇒ matter waves exist!
- Then what is the wavelength?

For photons :

For matter must be the same :

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Bohr's Atom



- Bohr model of the atom
- Quantum structure: e^- orbits are matter waves
- Semiclassical: mixes Newtonian & quantum ideas
- de Broglie waves ⇒ standing waves in atom
- e^- orbits are circular
- Only certain radii, speeds allowed—quantized states ⇒ only certain allowed energies
- During e^- transitions between states, photon emitted
- So, photon energies quantized ⇒ spectral lines

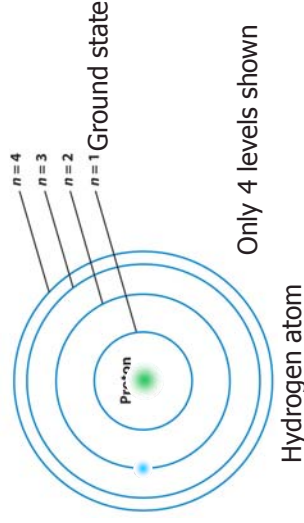
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Atomic Structure



- 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*



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Explaining



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

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

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Orbit



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

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Orbit



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

$$\text{(cgs charge units : } e_{\text{cgs}}^2 = k e_{\text{SI}}^2 = e_{\text{SI}}^2 / 4\pi\epsilon_0 \text{)}$$

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Orbit



- So, if the electron is in an orbit, what is the force?
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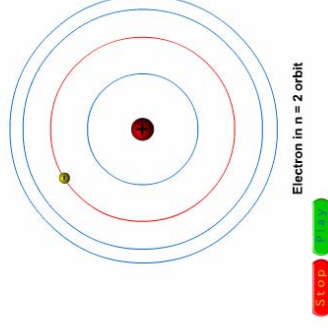
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How Do Spectrum Lines Form?



- 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

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

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

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

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Lambda, Lambda, Lambda



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

Rydberg constant

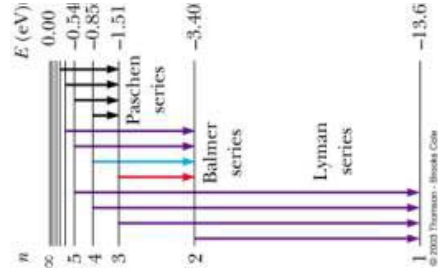
$$\lambda_\gamma = \frac{1}{R} \frac{n_a^2 n_b^2}{n_a^2 - n_b^2}$$

With $n_b=2$, we obtain the Balmer result!

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Series



new unit: $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$

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

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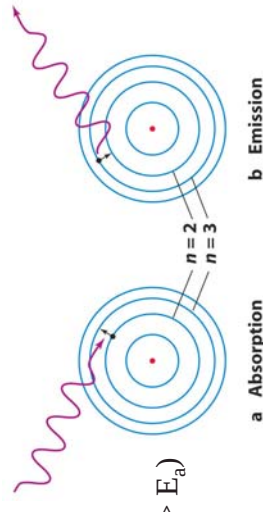
How Do Spectrum Lines Form?



- 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



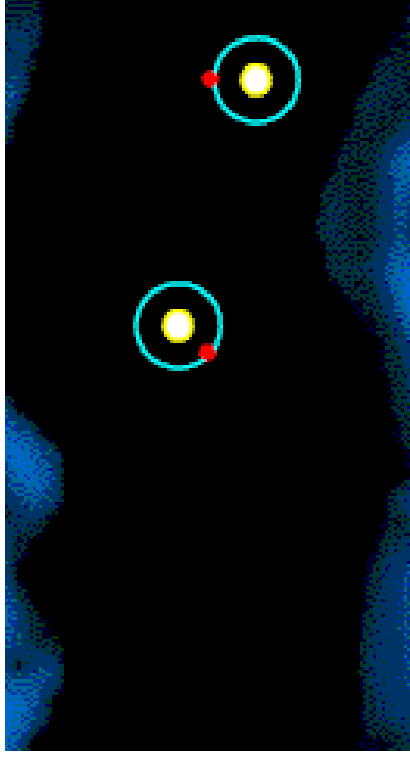
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Atom Collisions



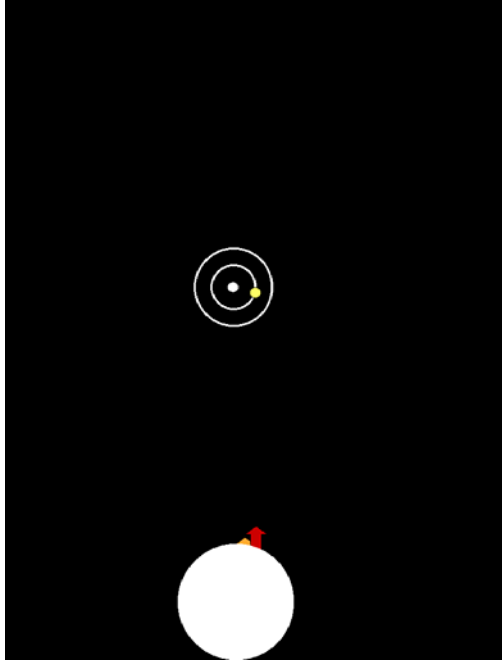
- Electrons get knocked-up to higher energy levels by collisions



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Creation of Absorption and Emission Line Spectra



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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 ($n = 1$)?

$$E_{\text{ionize}} = -E_1 = -\left(\frac{-Rch}{n^2}\right) = Rch = -13.6\text{eV}$$

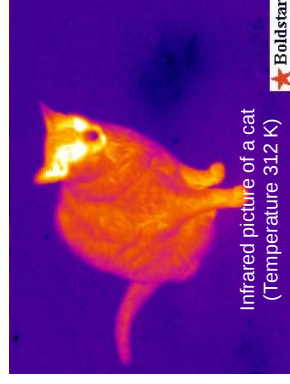
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Blackbody Radiation

- 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



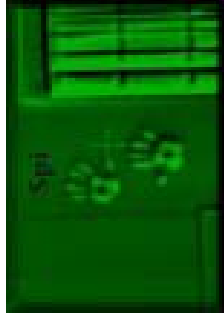
Visible-light picture of a stove element
Astronomy 210 Spring 2005 (Temperature ~ 400 K)

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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_TTWS320.htm
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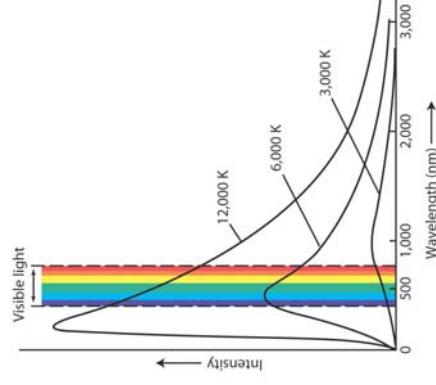
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The Spectrum of Blackbody Radiation



- 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.



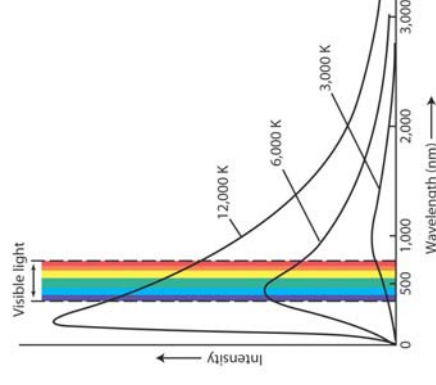
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Wein's Law

$$\lambda_{\max} = \frac{2.9 \times 10^{-3} \text{ mK}}{T}$$

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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
- A clear exception is a laser pointer.
 - Why?
- The spectrum of this ideal, only depends on its temperature!



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Think-Pair-Share



Which star is hotter?

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



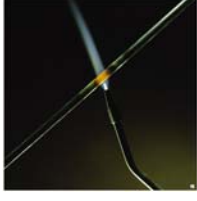
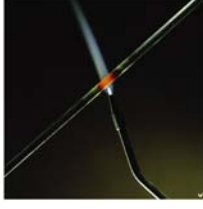
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Red Hot?



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



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The Spectrum of Blackbody Radiation



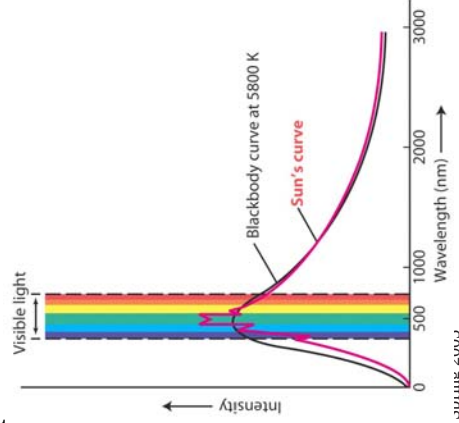
Sun's maximum is at ≈ 500 nm

$$\text{So, } T \approx \frac{2.9 \times 10^{-3} \text{ m K}}{500 \times 10^{-9} \text{ m}} = 5800 \text{ K}$$

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 $\leftrightarrow$ Temperature!



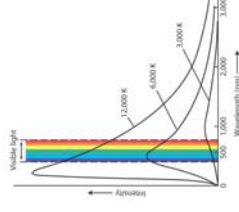
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Blackbody Flux-ed



- 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 unit area per unit time



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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 unit area per unit time

$$\sigma = 5.67 \times 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4} \quad \text{Stefan - Boltzmann}$$

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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

$$L_{\odot} = 3.85 \times 10^{26} \text{ W}$$

$$= \frac{3.85 \times 10^{26} \text{ W}}{4\pi(7.0 \times 10^8 \text{ m})^2} = 6.3 \times 10^7 \frac{\text{W}}{\text{m}^2}$$

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

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