

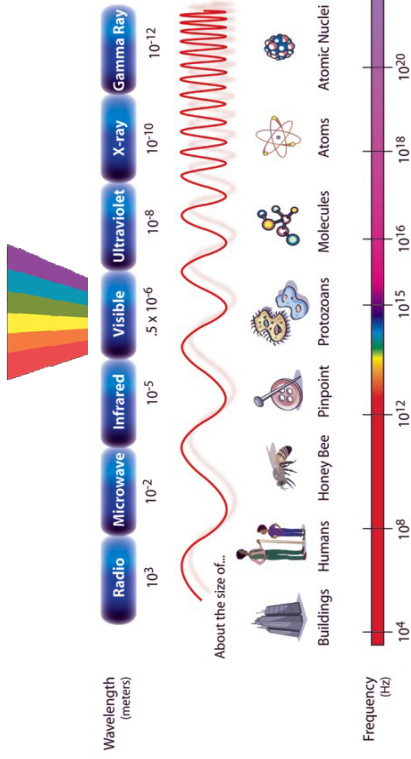


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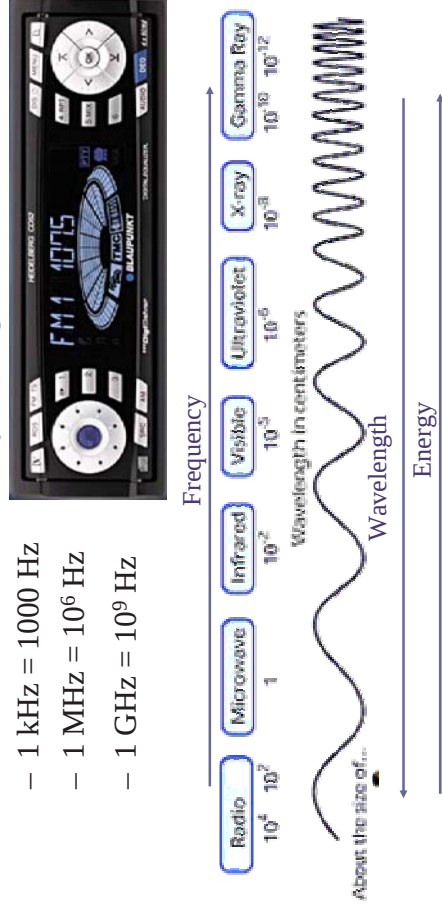
The electromagnetic spectrum

- Visible light is only a tiny portion of the full electromagnetic spectrum
- Red light has longer wavelength/lower frequency/lower energy than blue light
- Divisions between regions are really only from biology or technologies.

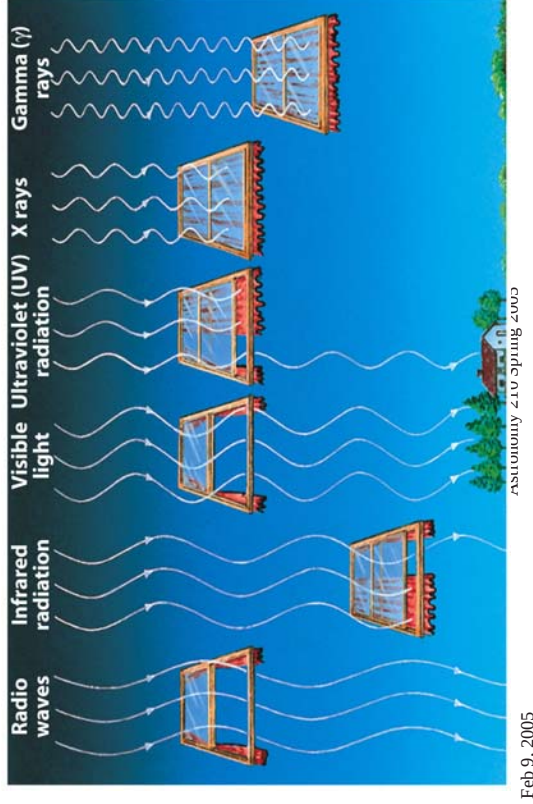


Frequency

- The frequency of light depends on its color.
- The unit is Hertz, equivalent to 1 cycle a second.
- For radio waves, we normally use larger units
 - 1 kHz = 1000 Hz
 - 1 MHz = 10^6 Hz
 - 1 GHz = 10^9 Hz



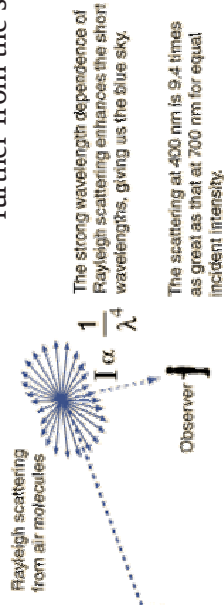
The atmosphere absorbs some wavelengths and not others



Why is the Sky Blue?

Atmospheric nitrogen and oxygen scatter the blue part of the spectrum via Rayleigh scattering (when molecules are up to $\lambda/10$).

Note that the blue of the sky is more saturated when you look further from the sun.



Light is also a Particle!

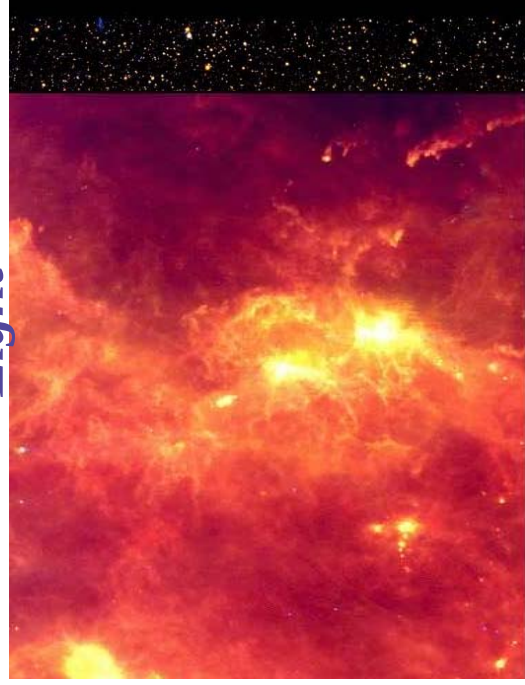
- In 1905, Einstein showed that light also behaves as a particle
 - Light particles are called **photons** (*symbol* γ)
 - The energy of a photon increases as the frequency of the light increases (and the wavelength decreases)
- $$E = hf$$
- Planck's constant ($h=6.63 \times 10^{-34}$ J s)
 - That means that a 100-watt light bulb emits 3×10^{20} photons per second!
 - What does this mean for a laser pointer?



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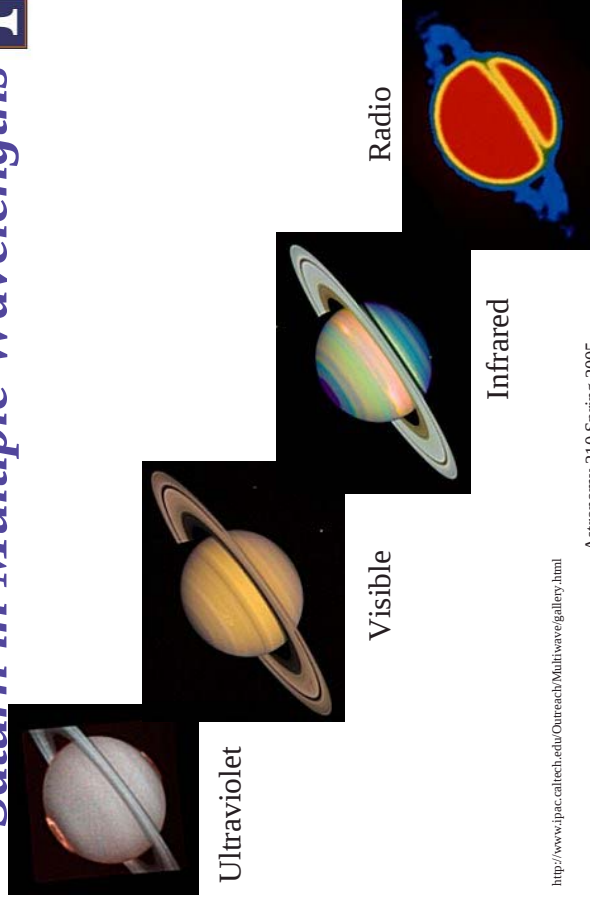
Orion in Visible and Infrared Light



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Saturn in Multiple Wavelengths

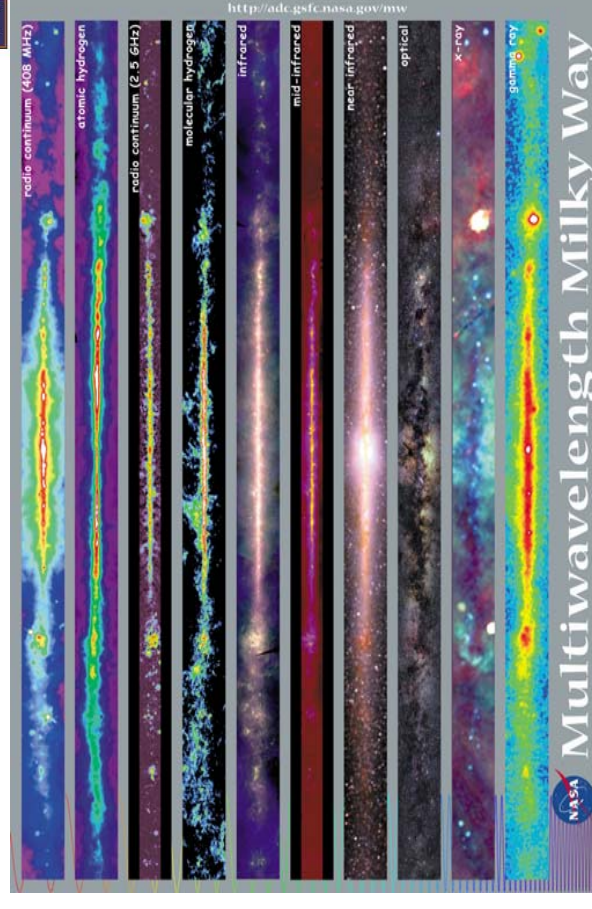


<http://www.jpl.nasa.gov/ourreach/Multiwave/gallery.html>

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Multi-Wavelength Galaxy



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The Big Picture



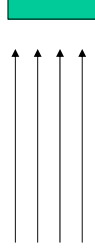
- Today, we can observe in almost every part of the electromagnetic spectrum
- Only 100 years ago, we were blind to the big picture of the Universe
- As we begin to piece together the big picture, our understanding of the cosmos grows

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Flux-ing Amazing



- Define the luminosity of a source as the energy flow of the source $L = dE/dt$
- Define the flux of light:
 - Energy flow per unit area per unit time



$$dE = FAdt$$

$$F = \frac{1}{A} \frac{dE}{dt}$$

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Which is Brighter?



- The Moon or the streetlamp?
- Why?
- *Apparent brightness* and *luminosity* difference.



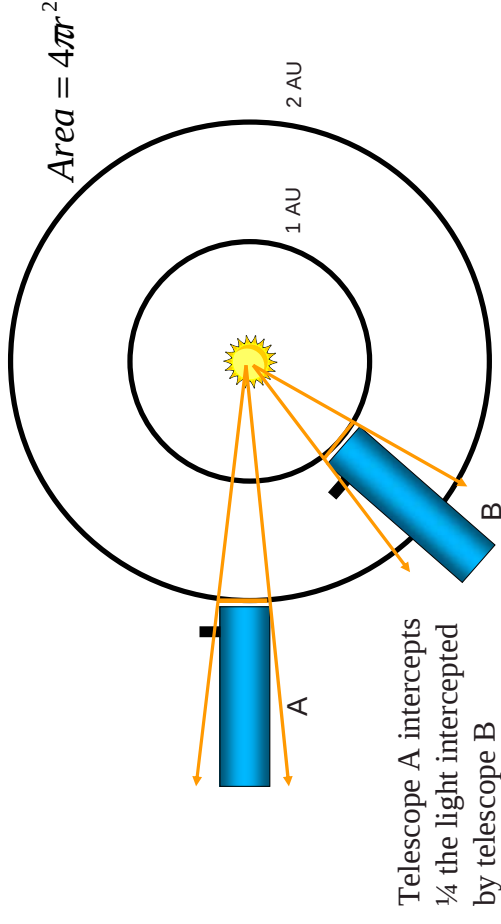
© www.danrheller.com
<http://www.danrheller.com/images/California/CalCoastSantaCruz/SlideShow/img13.html>
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Why do more distant objects look so much fainter?



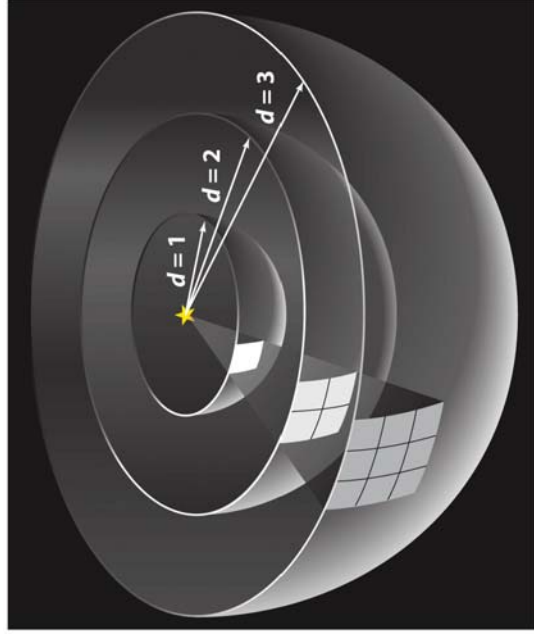
- More distant stars of a given luminosity appear dimmer
- Apparent brightness drops as square of distance



Telescope A intercepts 1/4 the light intercepted by telescope B

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Same number of Photons, but more area.



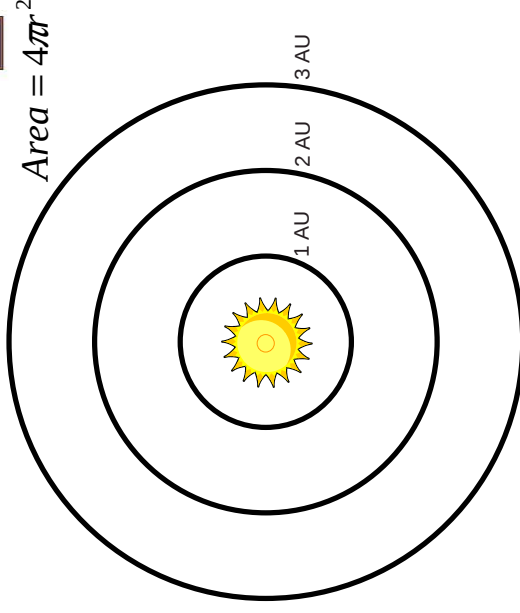
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Flux and Distance



- Area of concentric spheres increases as the square of their radii
- Same amount of light passes through each sphere
- So amount of light per unit area (ie. **flux**) decreases as the inverse square of the distance

Radius	Area/4 π	Flux
1 AU	1 AU ²	1.00
2 AU	4 AU ²	0.25
3 AU	9 AU ²	0.11



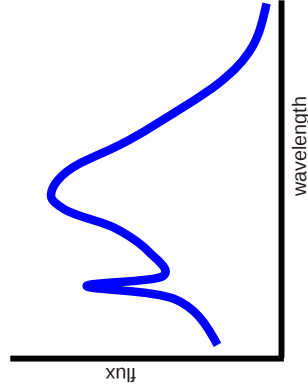
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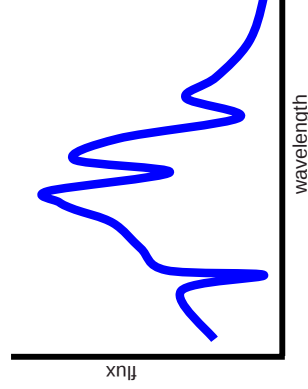
The Spectrum



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

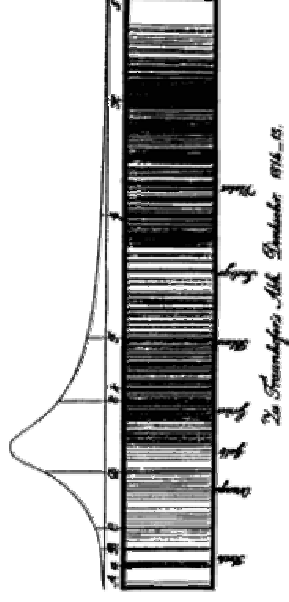
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Spectrum Lines



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



Joseph von Fraunhofer (1787-1826)

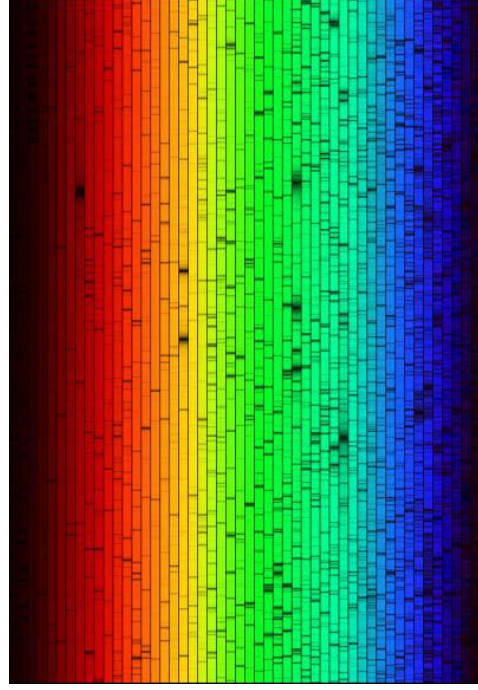


Prism spectrograph

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What Color is Sunlight?

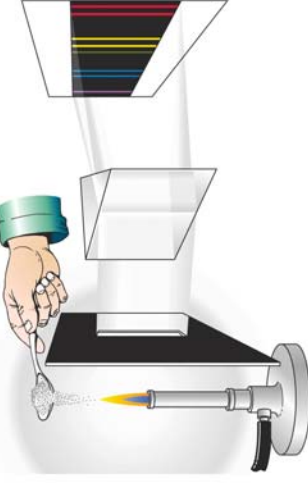


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<http://anwrp.gsfc.nasa.gov/apod/ap000815.html>

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

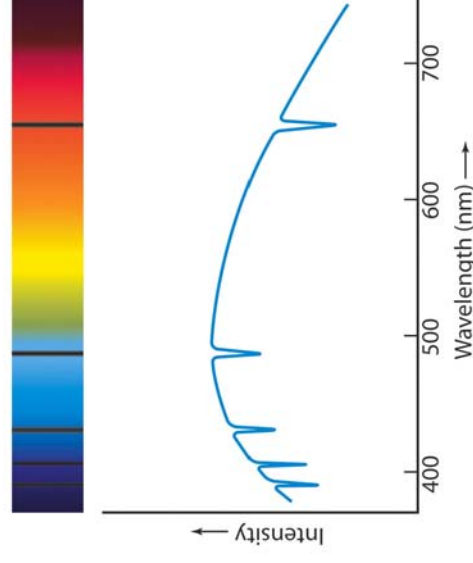
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Spectrum Lines



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



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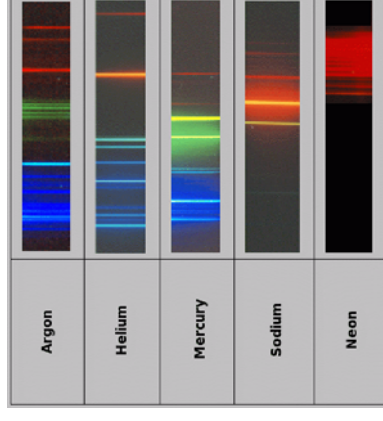
Spectrum Lines = Fingerprints



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

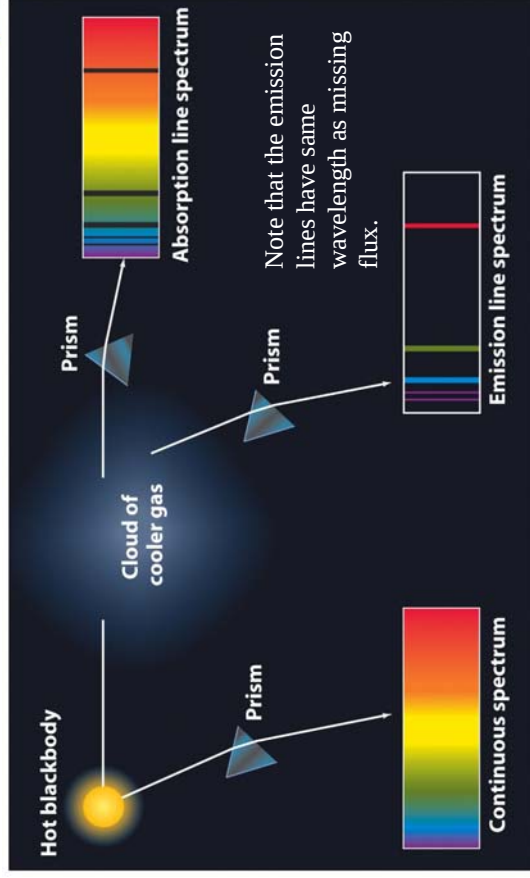


- In 1859, Gustav Kirchhoff discovered the conditions under which three basic types of spectra are formed:
 - A hot, dense object produces a **continuous spectrum**
 - A hot low-density gas produces an **emission-line spectrum**
 - A continuous spectrum source viewed through a cooler gas produces an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

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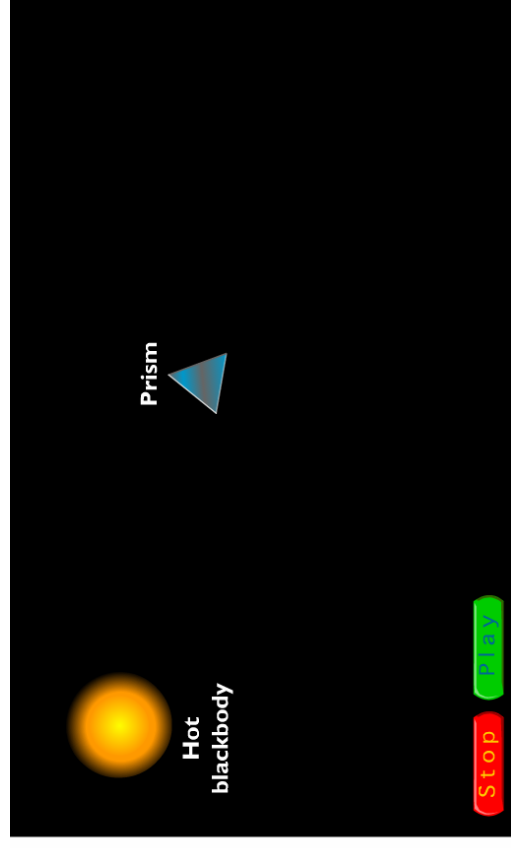
Kirchoff's Laws



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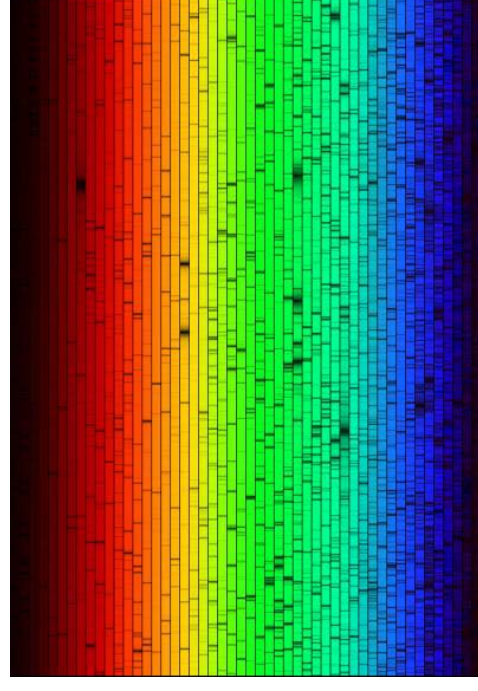
Kirchoff's Laws



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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...

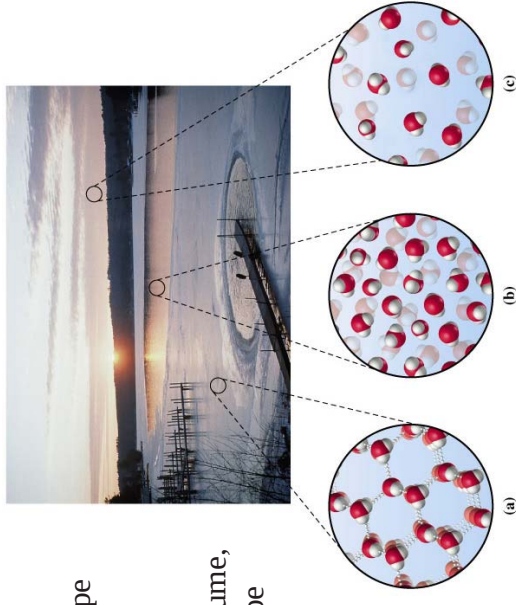
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States of Matter



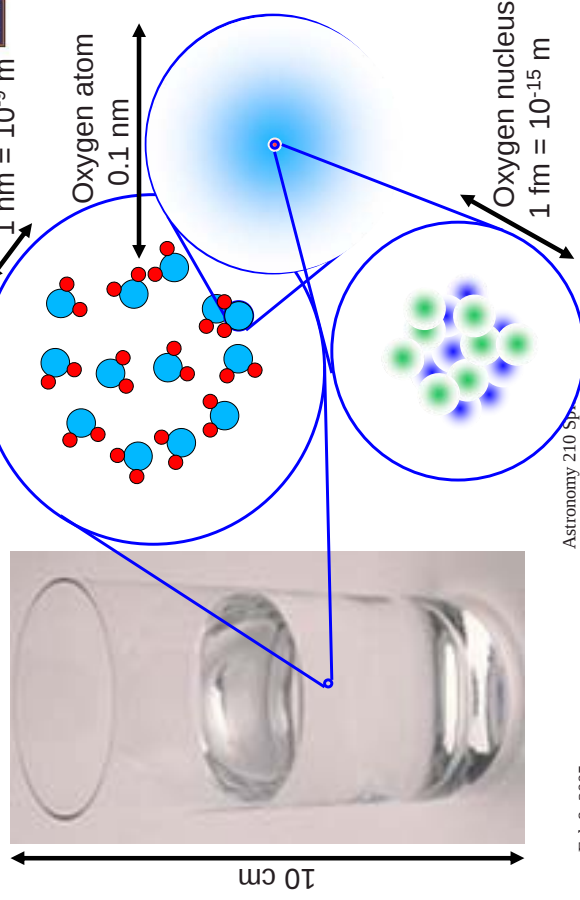
- Solid
 - Definite shape and volume
- Liquid
 - Definite volume, flexible shape
- Gas
 - Flexible shape *and* volume



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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

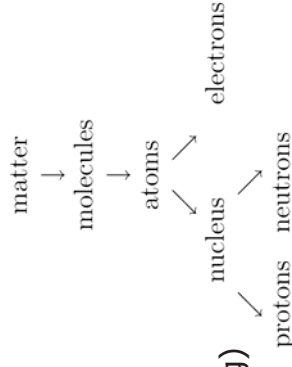
Negatively charged (charge -1)
Lightweight (mass 9.110×10^{-28} g)

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	Hs	Hassium	108	Mt	Meitnerium
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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?

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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 :

$$\lambda = \frac{c}{\nu} = \frac{c}{E/h} = \frac{hc}{E} = \frac{h}{p}$$

For matter must be the same :

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

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Bohr's Atom



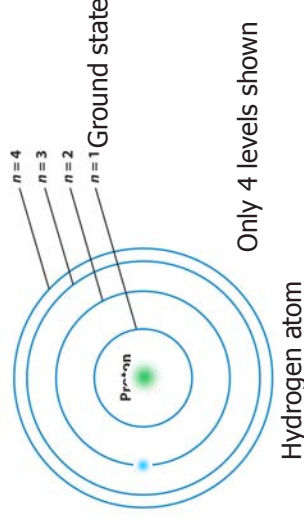
- Bohr model of the atom
- Quantum structure: e⁻ orbits are matter waves
- Semiclassical: mixes Newtonian & quantum ideas
- de Broglie waves ⇒ standing waves in atom
- e⁻ orbits are circular
- Only certain radii, speeds allowed—quantized states ⇒ only certain allowed energies
- During e⁻ transitions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