

Announcements

- Review: Tuesday, February 27
- All HWs and WS's will be available for pickup at the review
- Test #1: Thursday, February 29 in RH114 Closed book, closed notes. Bring a pencil and a simple calculator (no iphones or internet capable calculators)

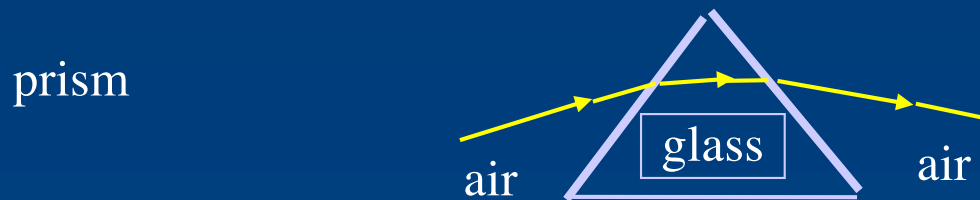
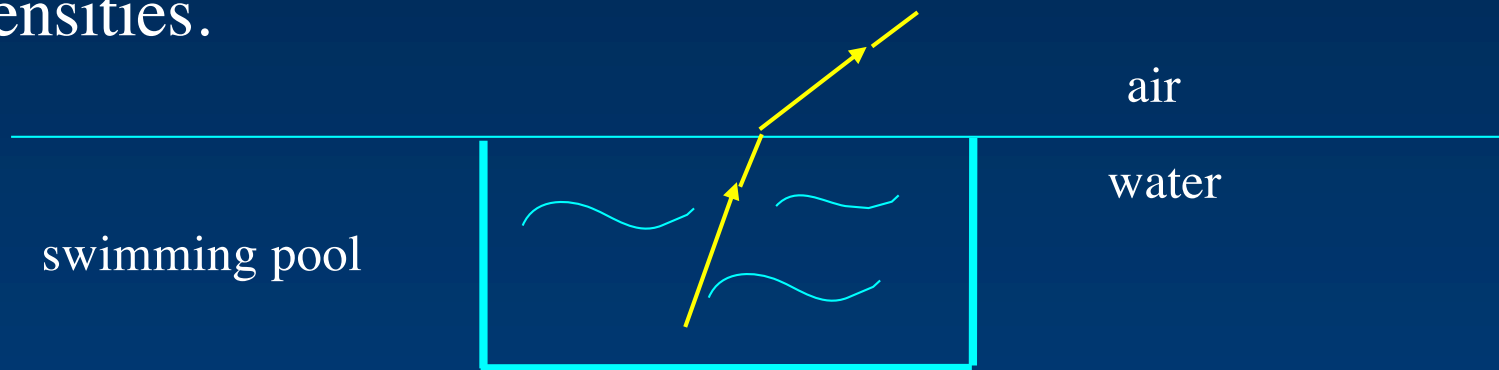
What is luminosity?

- Luminosity = total energy output from an object per second ($W = Js^{-1}$). Independent of distance - *intrinsic* property.
- Apparent brightness is how bright an object *appears* to be - this is what we actually measure ($Js^{-1}m^{-2}$, flux units). Depends on the distance.

Things that waves do

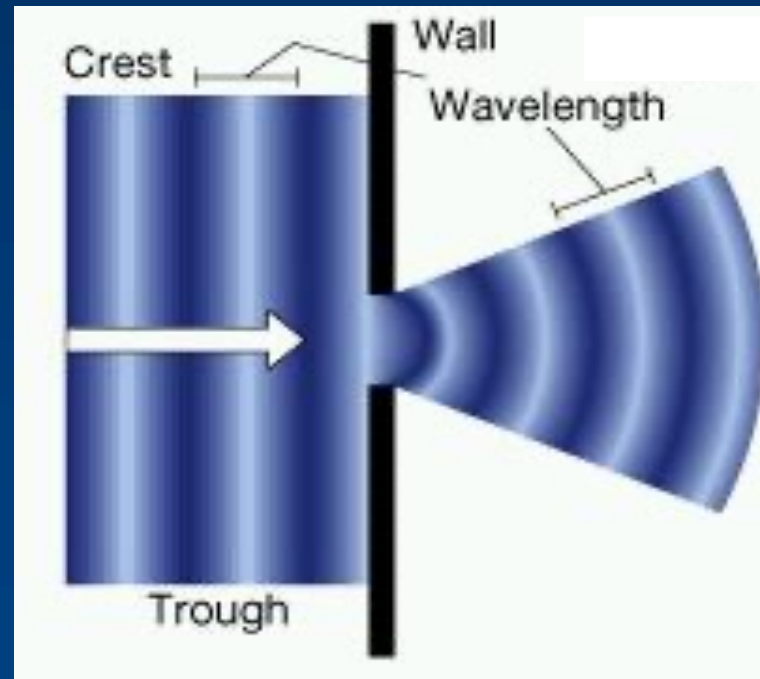
1. Refraction

Waves bend when they pass through material of different densities.



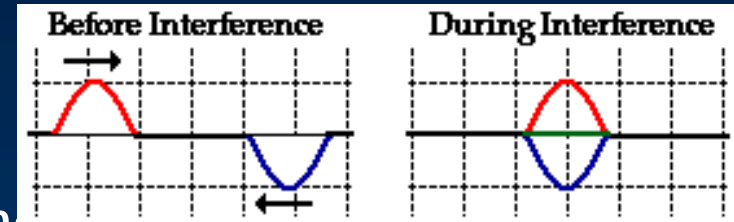
2. Diffraction

Waves bend when they go through a narrow gap or around a corner.

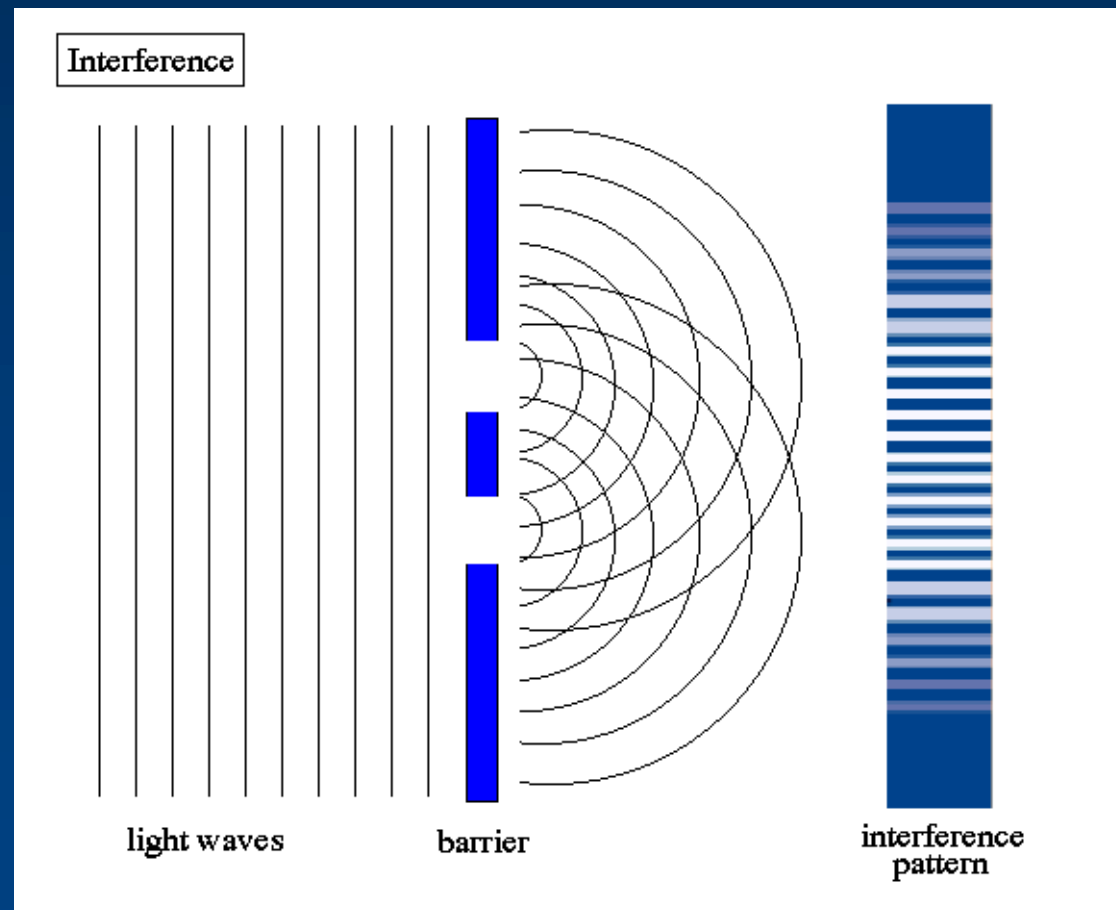


3. Interference

Waves can interfere with each other



Demo:
LASER fringes



How do radiation and matter interact?

- Emission - light bulb, star
- Absorption - your skin can absorb light - the absorbed energy heats your skin
- Transmission - glass and air lets light pass through
- Reflection and scattering - light can bounce off matter leading to reflection (in one direction) or scattering (in many directions)

The Nature of Light Part II:

Polarization of Light

Light as a particle

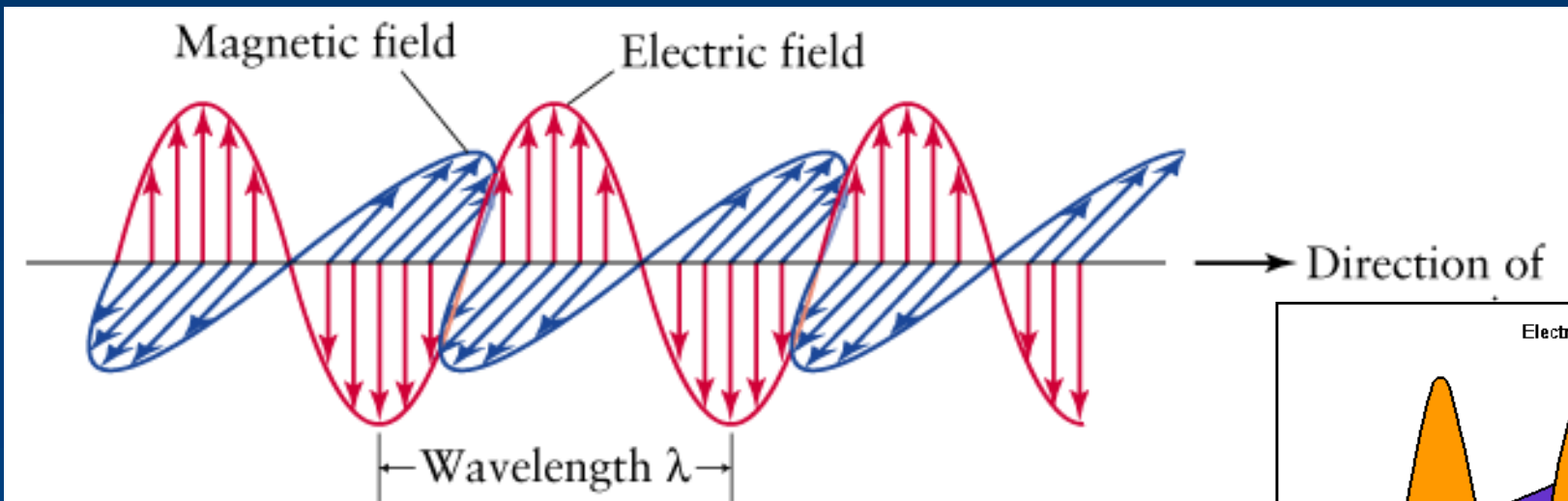
Atomic Structure

Emission and Absorption Lines

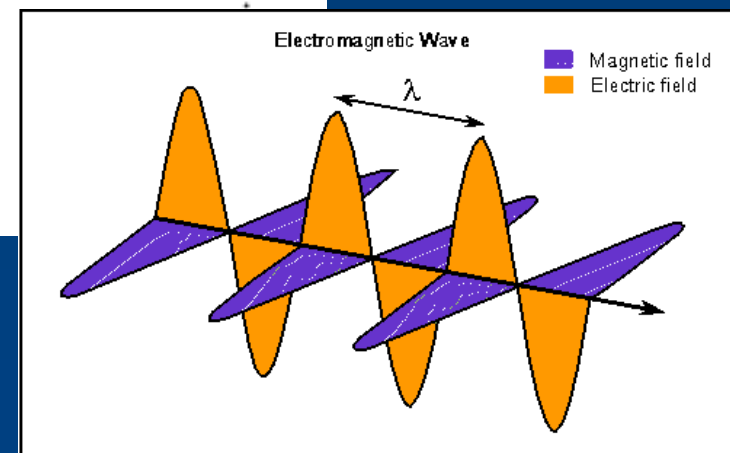
Doppler Effect

Electromagnetic waves

- EM waves: self propagating electric and magnetic fields (changes in strengths of E and M fields).
- Individual photons are polarized (direction of E field)
- Collection of photons can have a statistical polarization or be randomly oriented - DEMO



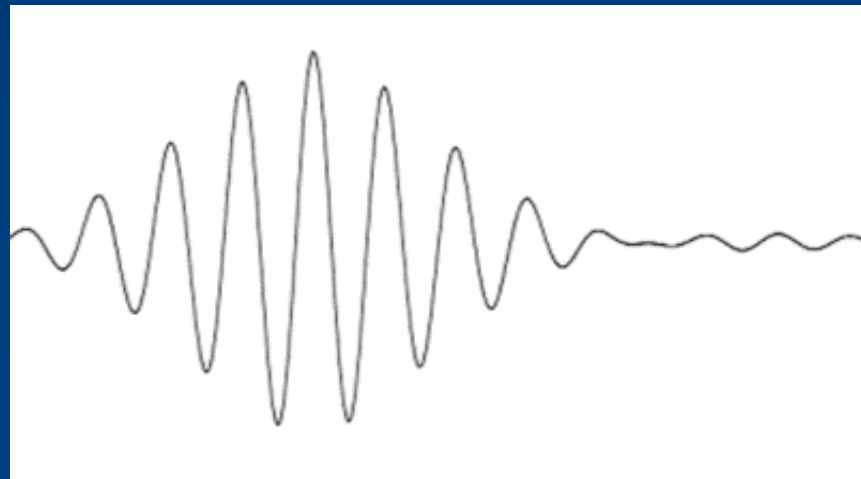
Different from other waves, since it doesn't need a medium in which to propagate!



The dual nature of light

Light often acts like a wave, but also can act like a particle – in interactions with atoms and molecules

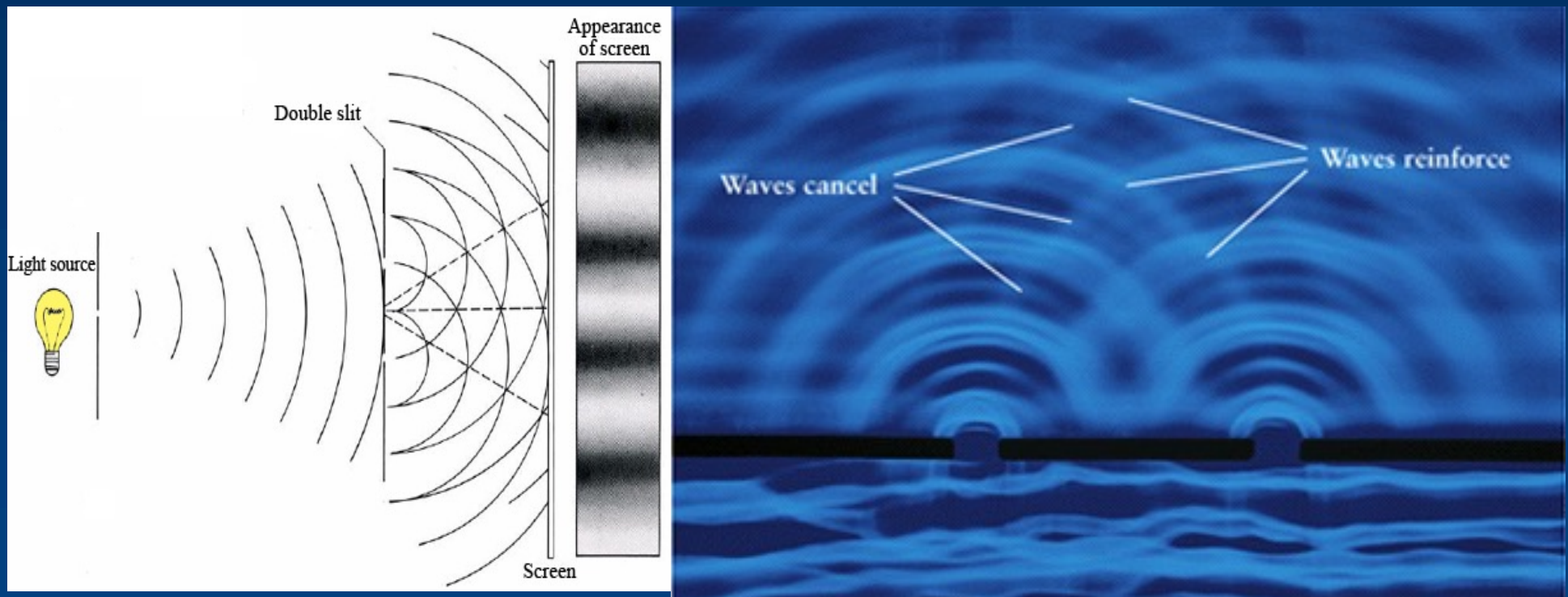
- The particles are called *photons*
- A photon is a massless particle that carries energy (and momentum) at the speed of light



Young's double slit experiment

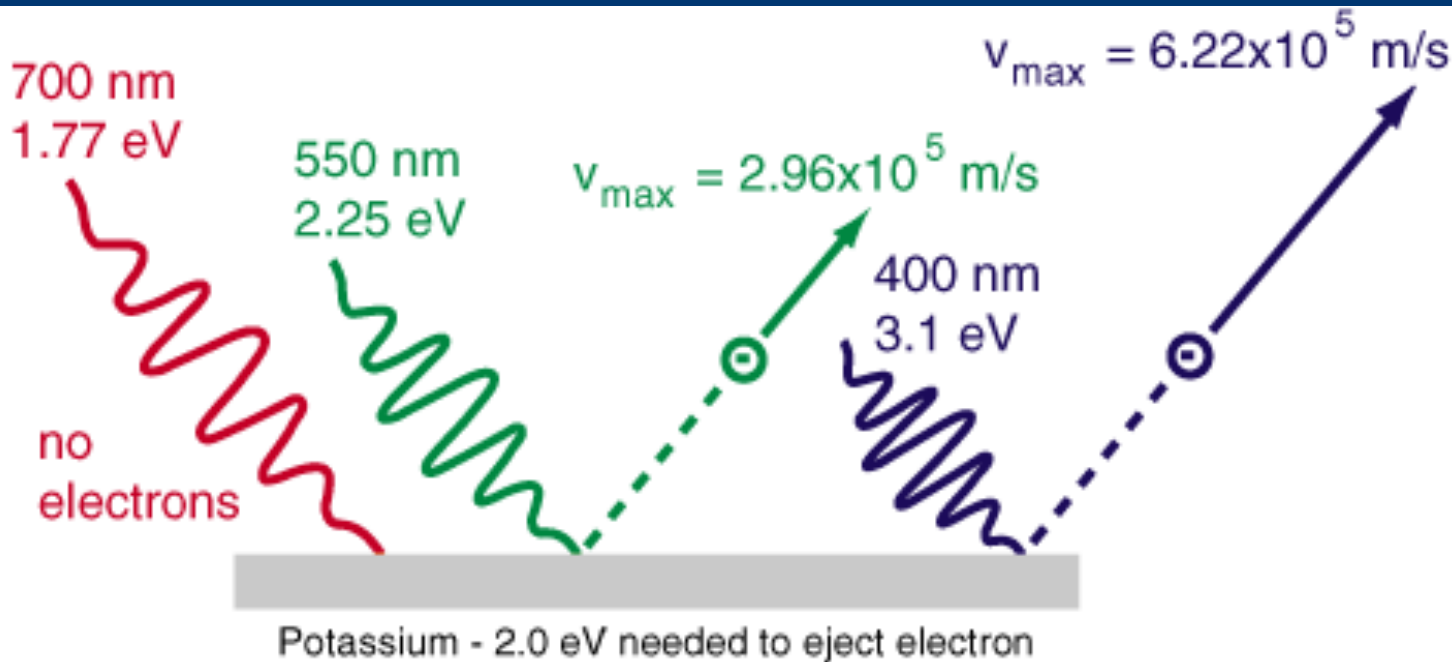
Demonstrates the wave-like nature of light:

Like water waves (right), EM waves can interfere



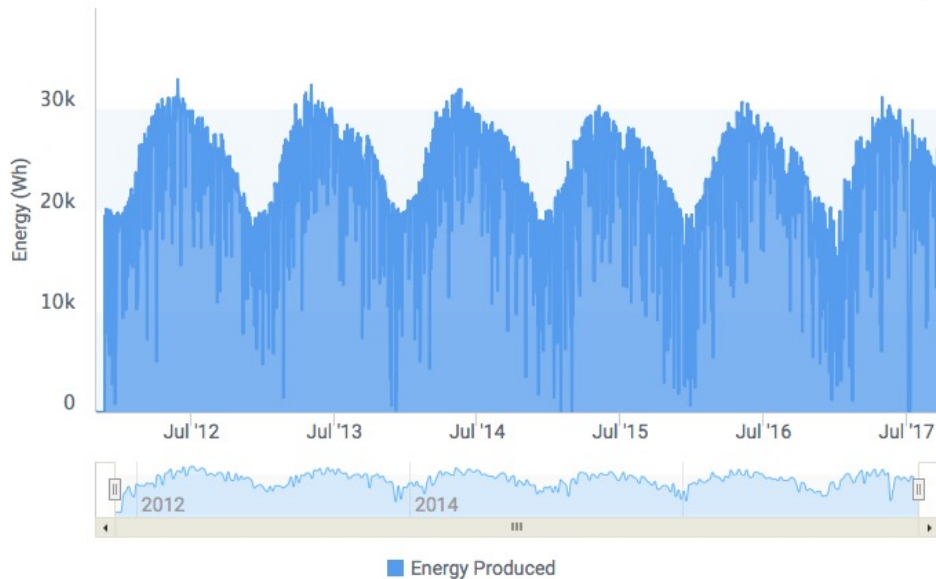
Photoelectric effect

- Demonstrates particle nature of light:
 - Light hitting a metal will knock out single electrons, but only if the frequency is high enough, not the intensity
 - Energy of photoelectrons depends only on incoming light frequency, not on intensity
 - Compare energy of wave \propto Amplitude²



(1 eV = 1.6×10^{-19} J – energy an electron gains by accelerating through an electric potential of 1 V)

Photovoltaics



Taylor7417 Full System

View Graph Reports Devices Events

Power: Past 7 Days Sep 15, 2017 - Sep 21, 2017

19 Microinverters 72°F
1 Envy Ethernet
Albuquerque, NM
System Normal

Full System

Energy Status

Today **919 Wh**
Peak: 1.50 kW at 9:20 AM
Latest: 563 W at 9:25 AM

Past 7 Days **147 kWh**

Month To Date **457 kWh**

Lifetime **46.5 MWh**

System Power **3.51kW**
Wed Sep 20, 2017 01:25 PM

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Photon energies

Explanation: can consider light as a stream of particles (photons), with energy dependent on frequency. Only photons with sufficient energy can liberate electrons from atoms.

$$E = hc/\lambda \text{ or equivalently}$$

$$E = h\nu$$

$$h = 6.6 \times 10^{-34} \text{ J s (Planck's constant)}$$

$$h = 4.1 \times 10^{-15} \text{ eV s}$$

Question: which has more energy, a photon of blue light, or of red light? UV? Radio?

Atomic structure

Nucleus contains particles with most of atom's mass:

Protons (positively charged)

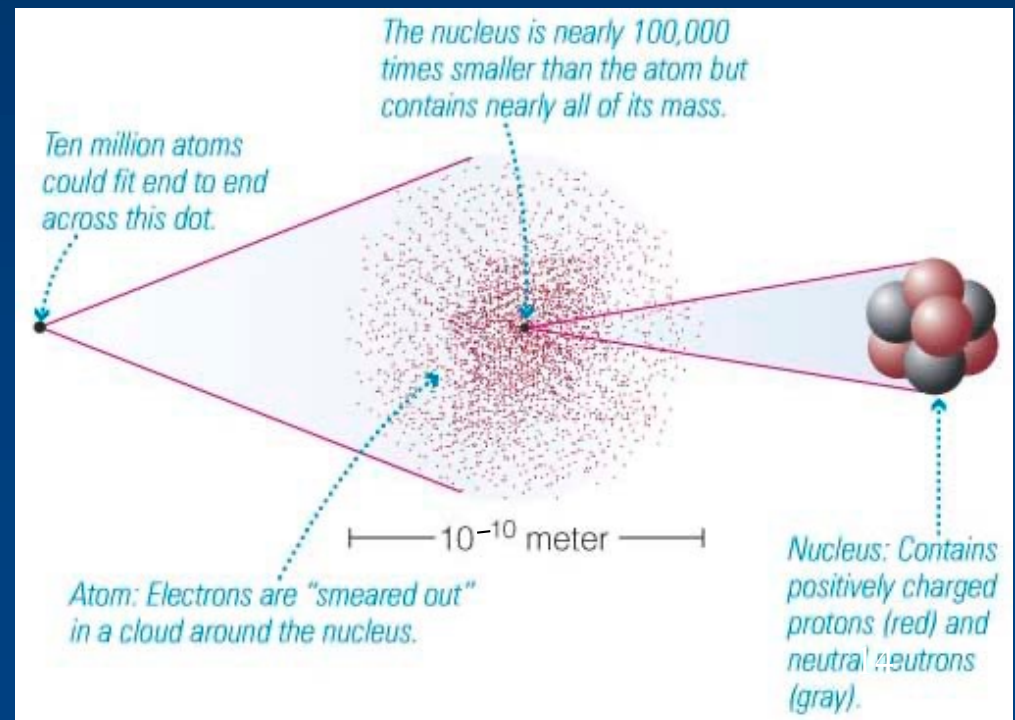
Neutrons (uncharged)

Electrons (negatively charged) in a cloud orbiting the nucleus

$$m_p = 1.6726 \times 10^{-27} \text{ kg}$$

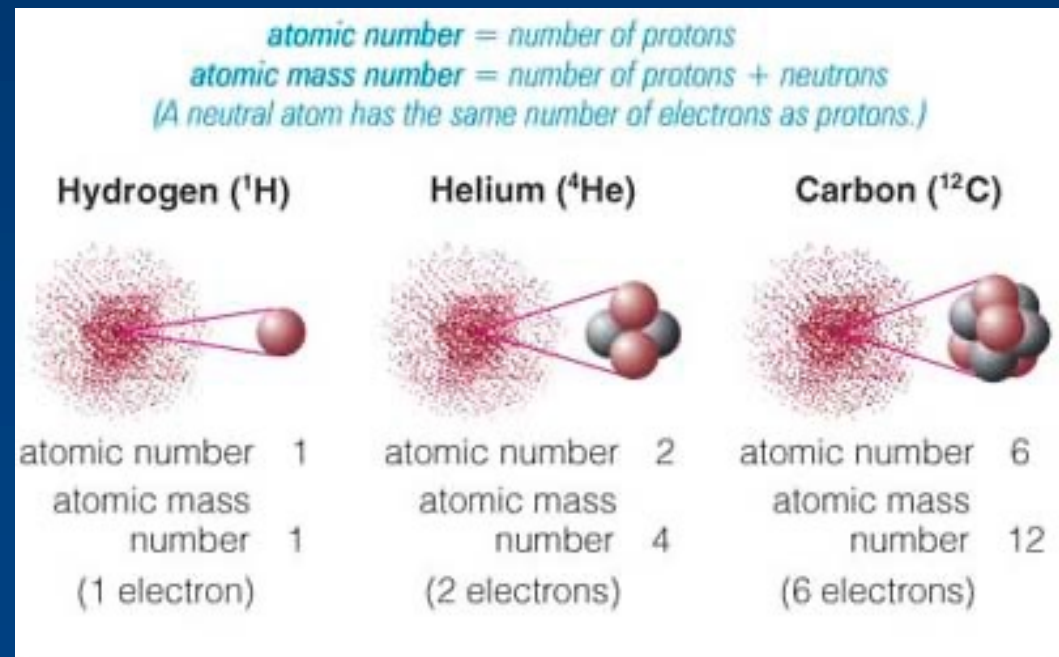
$$m_n = 1.6749 \times 10^{-27} \text{ kg}$$

$$m_e = 9.1094 \times 10^{-31} \text{ kg}$$



Chemical elements

- Atoms come in different *elements*, differentiated by the total number of protons in the nucleus.
- This is called the atomic number:
 - 1 proton: Hydrogen
 - 2 protons: Helium
 - 3 protons: Lithium
 - Etc.



Periodic Table of the Elements

1 IA New Original	2 IIA											13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA	
1 H Hydrogen 1.00794																	2 He Helium 4.002602	
2 3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797	
3 11 Na Sodium 22.989770	12 Mg Magnesium 24.3050	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8 VIII	9 VIII	10 VIII	11 IB	12 IIB	13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.453	18 Ar Argon 39.948	
4 19 K Potassium 39.0983	20 Ca Calcium 40.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.867	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938049	26 Fe Iron 55.8457	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.409	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.798	
5 37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium (98)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.293	
6 55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 to 71		72 Hf Hafnium 178.49	73 Ta Tantalum 180.9479	74 W Tungsten 183.84	75 Re Rhenium 186.207	76 Os Osmium 190.23	77 Ir Iridium 192.217	78 Pt Platinum 195.078	79 Au Gold 196.96655	80 Hg Mercury 200.59	81 Tl Thallium 204.3833	82 Pb Lead 207.2	83 Bi Bismuth 208.98038	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
7 87 Fr Francium (223)	88 Ra Radium (226)	89 to 103		104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (269)	109 Mt Meitnerium (268)	110 Ds Darmstadtium (271)	111 Rg Roentgenium (272)	112 Uub Ununbium (285)	113 Uut Ununtrium (284)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (288)	116 Uuh Ununhexium (292)	117 Uus Ununseptium	118 Uuo Ununoctium

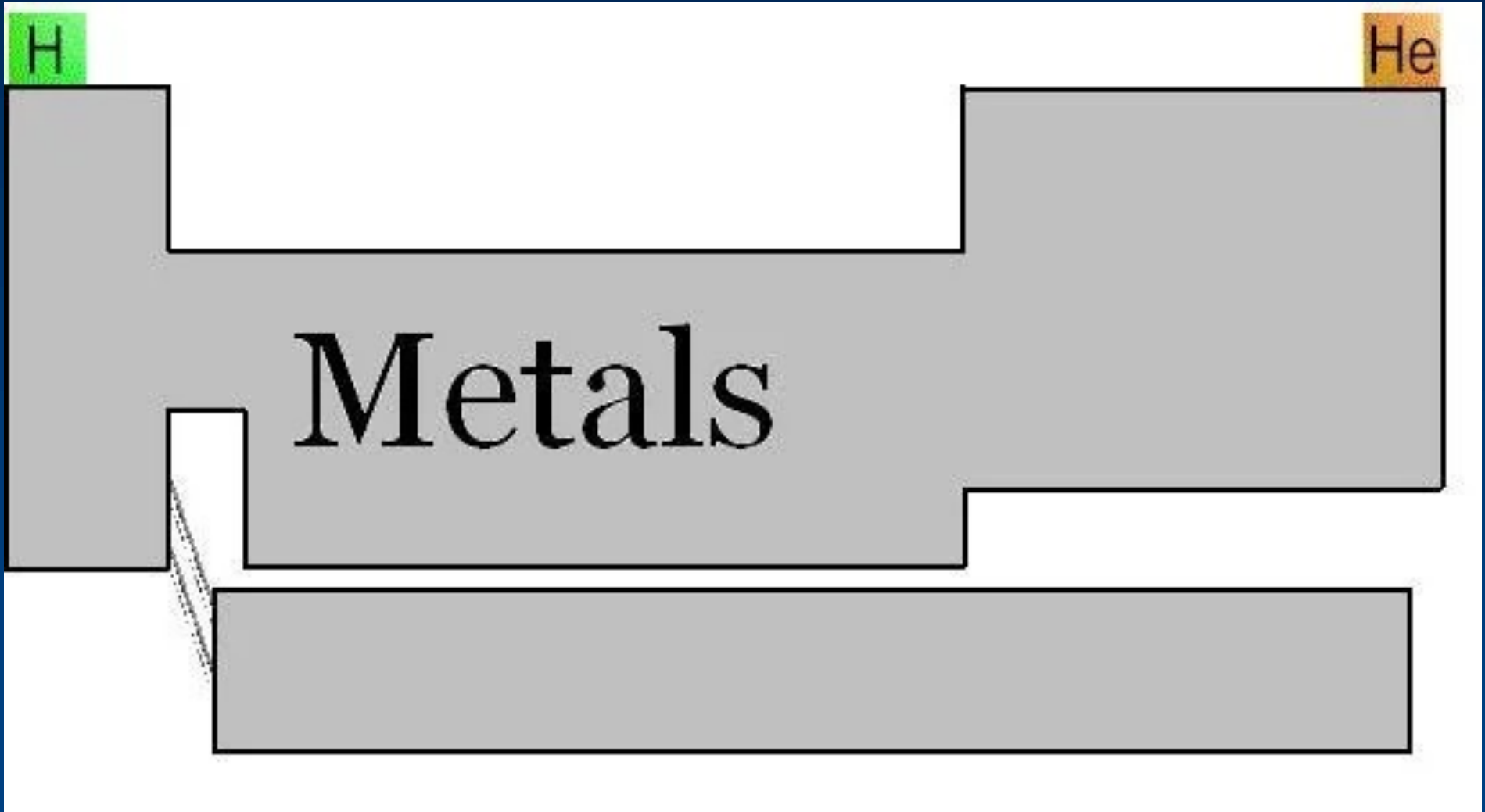
Atomic masses in parentheses are those of the most stable or common isotope.

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Note: The subgroup numbers 1-18 were adopted in 1984 by the International Union of Pure and Applied Chemistry. The names of elements 112-118 are the Latin equivalents of those numbers.

57 La Lanthanum 138.9055	58 Ce Cerium 140.116	59 Pr Praseodymium 140.90765	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.500	67 Ho Holmium 164.93032	68 Er Erbium 167.259	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967
89 Ac Actinium (227)	90 Th Thorium 232.0381	91 Pa Protactinium 231.03588	92 U Uranium 238.02891	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

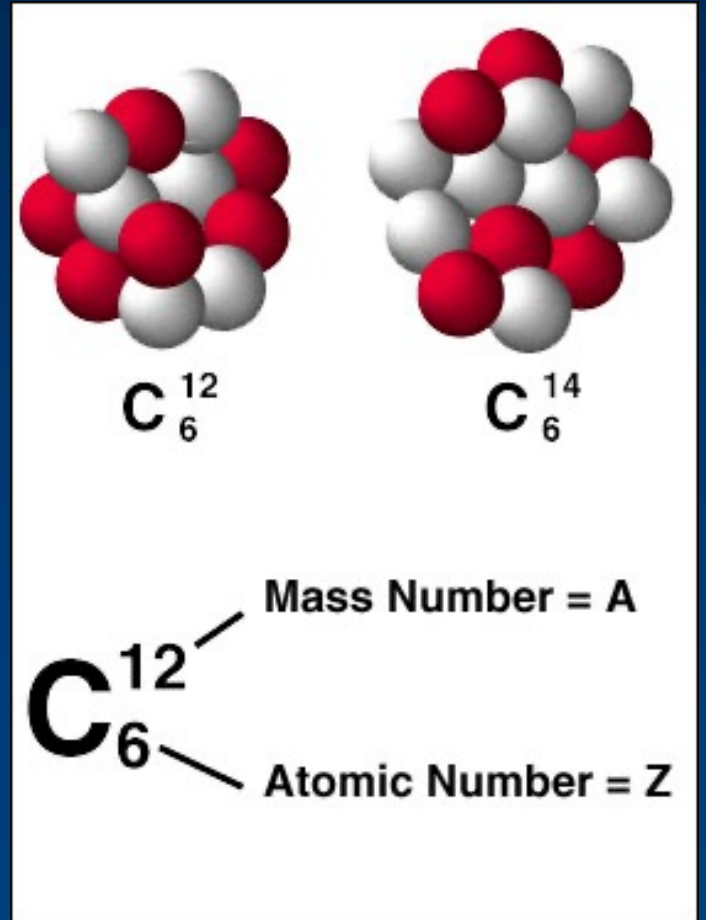
Astronomers Periodic Table





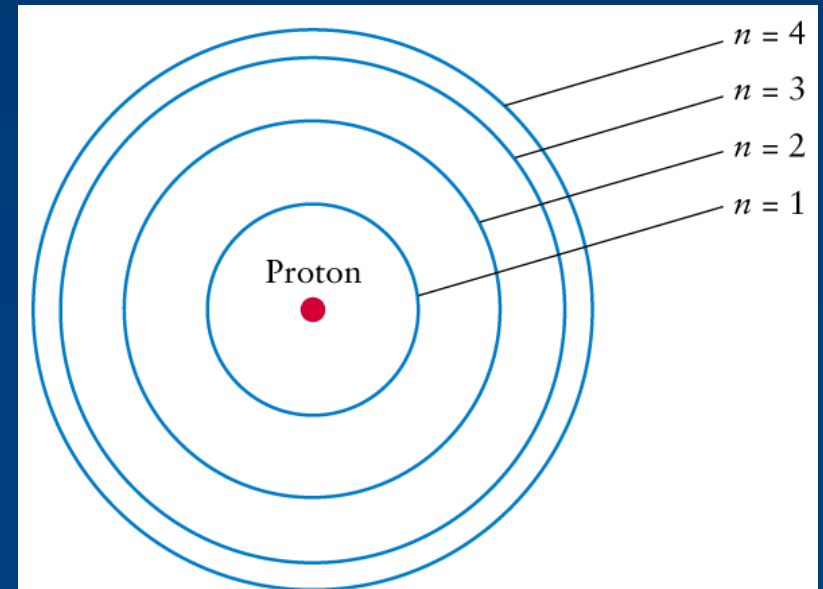
Isotopes of an element

- Same number of protons, but different number of neutrons.
- ^{12}C has 6 protons and 6 neutrons
- ^{13}C has 6 protons and 7 neutrons
- ^{14}C has 6 protons and 8 neutrons
But is unstable (half-life 5730 years)



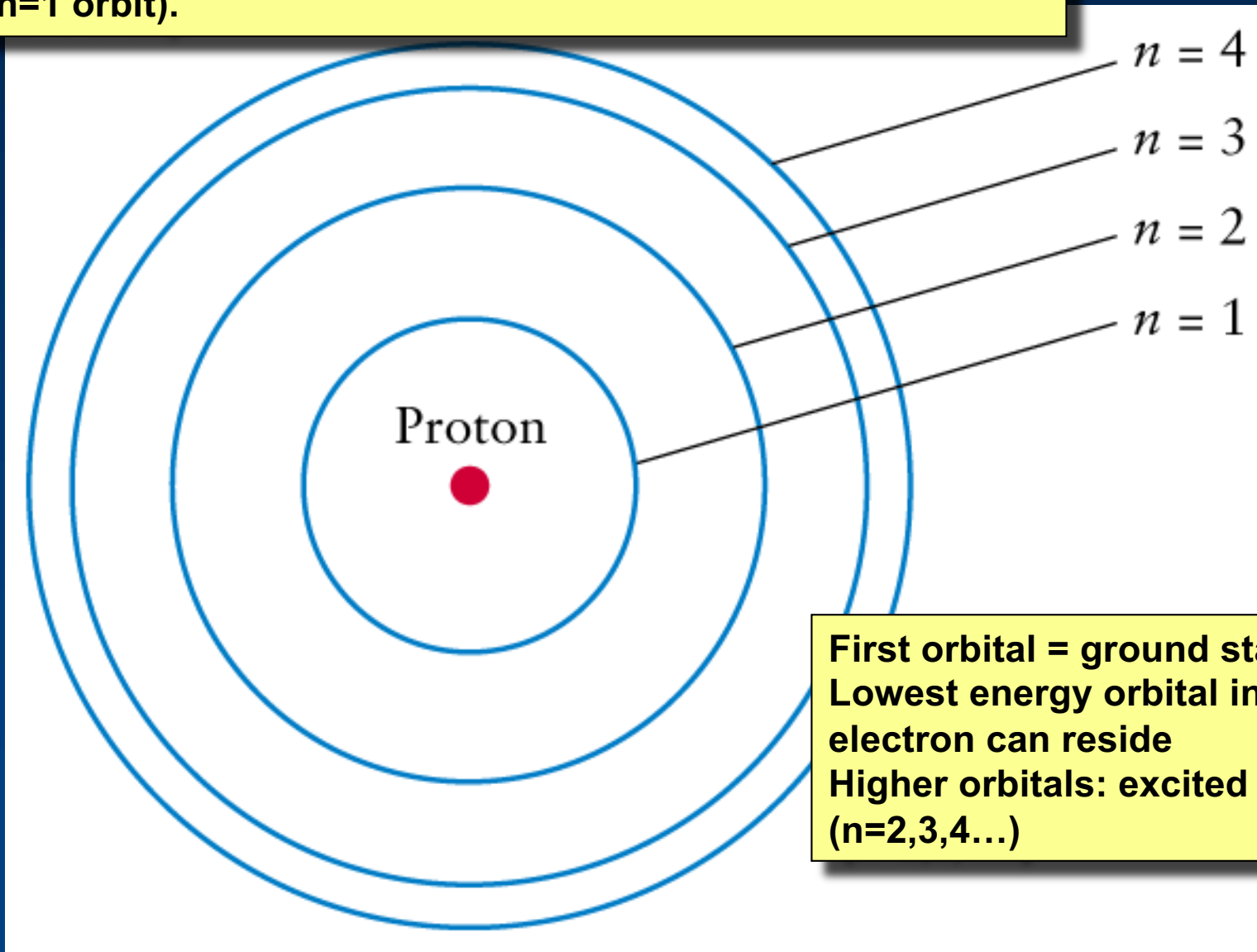
Bohr model of the H atom (1913)

- For practical purposes we can ignore fuzziness of electrons and consider them as discrete particles. Consider H:
- Proton and orbiting electron attracted. Takes energy to increase separation. Without energy, electron remains in “ground state” ($n=1$)
- But, only certain discrete orbitals, or energies, allowed
- Electron in “excited” state ($n>1$) quickly decays to lower levels.



The simple Bohr model for the hydrogen atom: a single electron orbiting a single proton (the nucleus).

The different energy levels represent allowed orbitals for electrons (not to scale, the $n=2,3,4$ orbits should be 4, 9 and 16 times larger than the $n=1$ orbit).

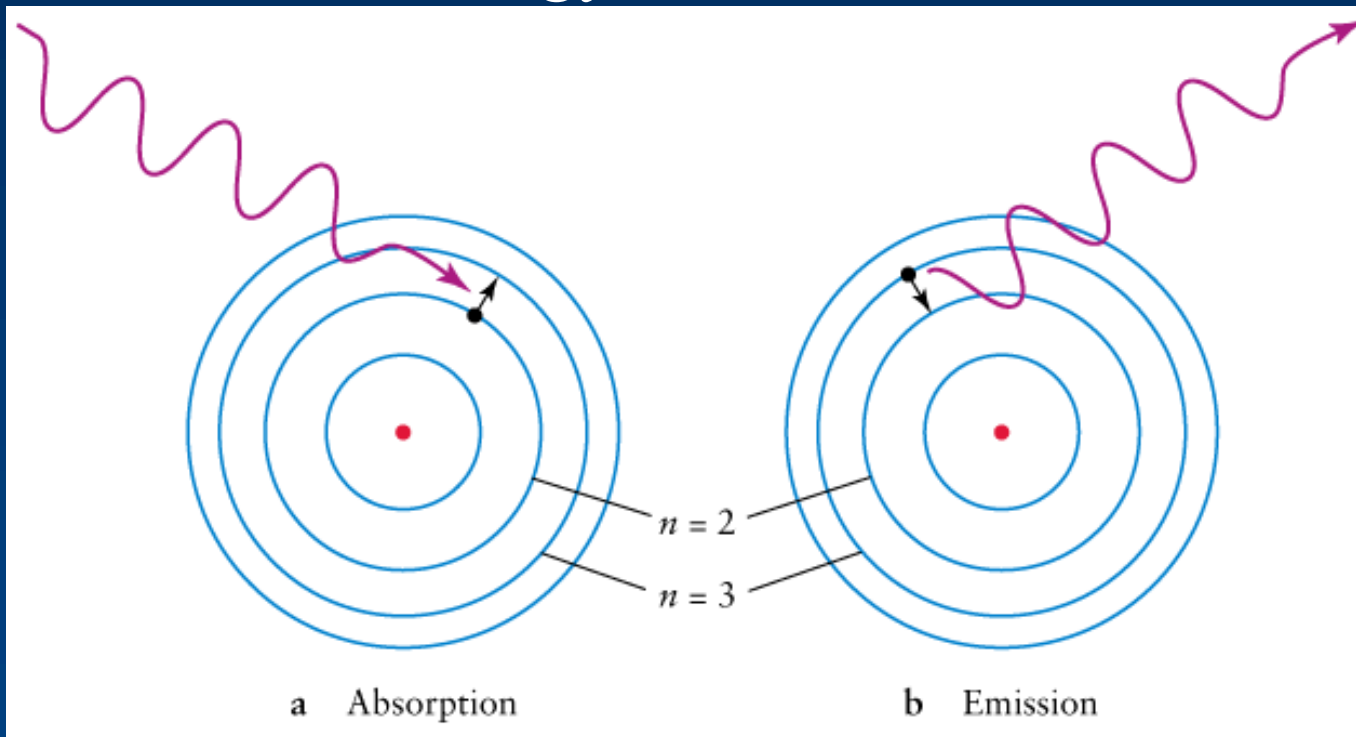


First orbital = ground state ($n=1$).
Lowest energy orbital in which the electron can reside
Higher orbitals: excited states ($n=2,3,4\dots$)

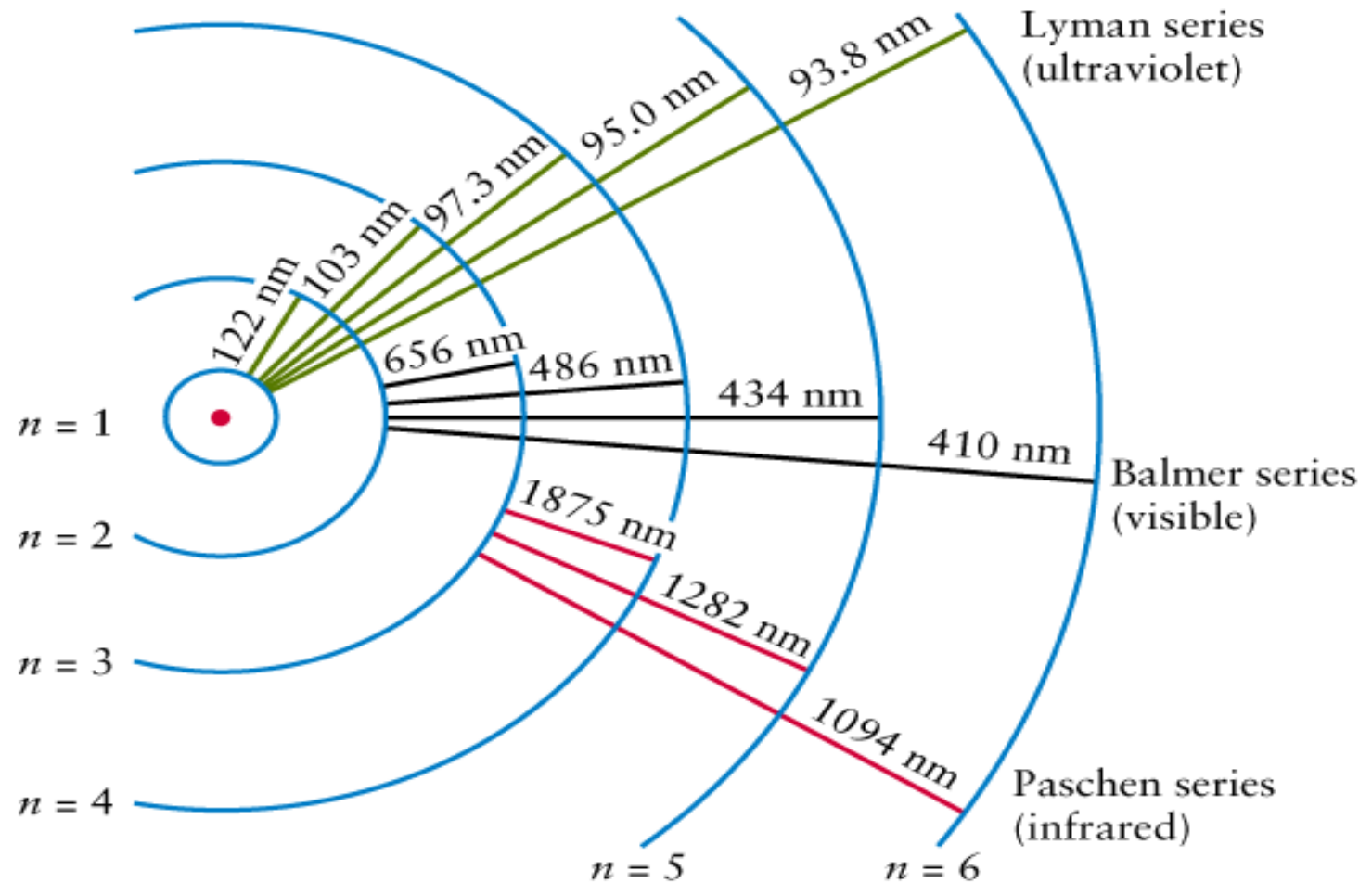
Emission and Absorption

- Electrons can get into excited states by either
 - Colliding (with other atoms or free electrons)
 - Absorbing photons (of specific energy)
- Absorption: only photons with exact excitation energy are absorbed, ALL others pass through unaffected.
- Electrons get out of excited states by emitting photons in random directions.

- An atom can **absorb** a photon, causing electron to jump up to a higher energy level.
- An atom can **emit** a photon, as an electron falls down to a lower energy level.



- May jump more than one level, and fall back down by various paths, emitting multiple photons.



Bohr formula for hydrogen wavelengths

$$\frac{1}{\lambda} = R \left(\frac{1}{N^2} - \frac{1}{n^2} \right)$$

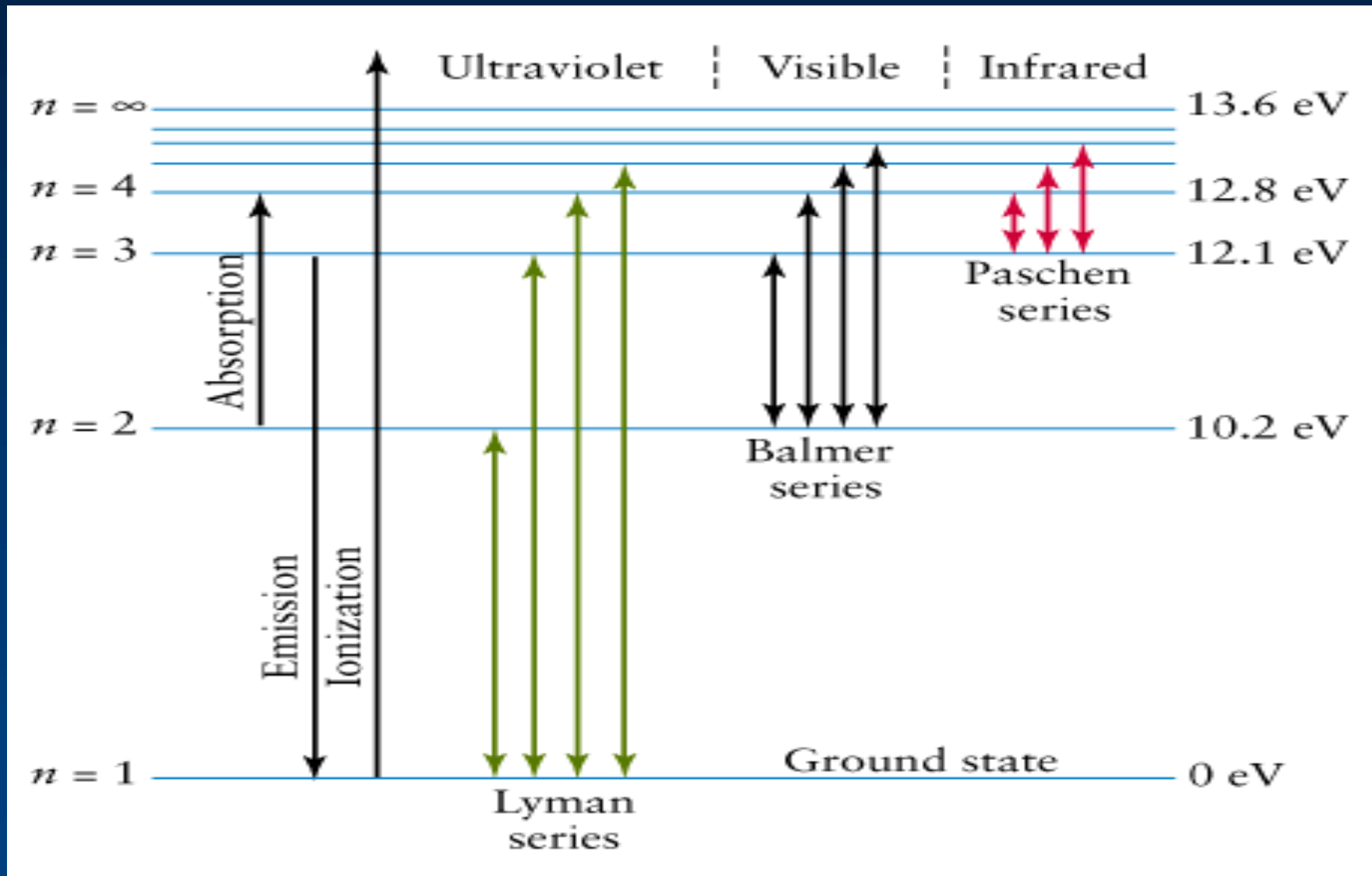
N = number of inner orbit

n = number of outer orbit

R = Rydberg constant = $1.097 \times 10^7 \text{ m}^{-1}$

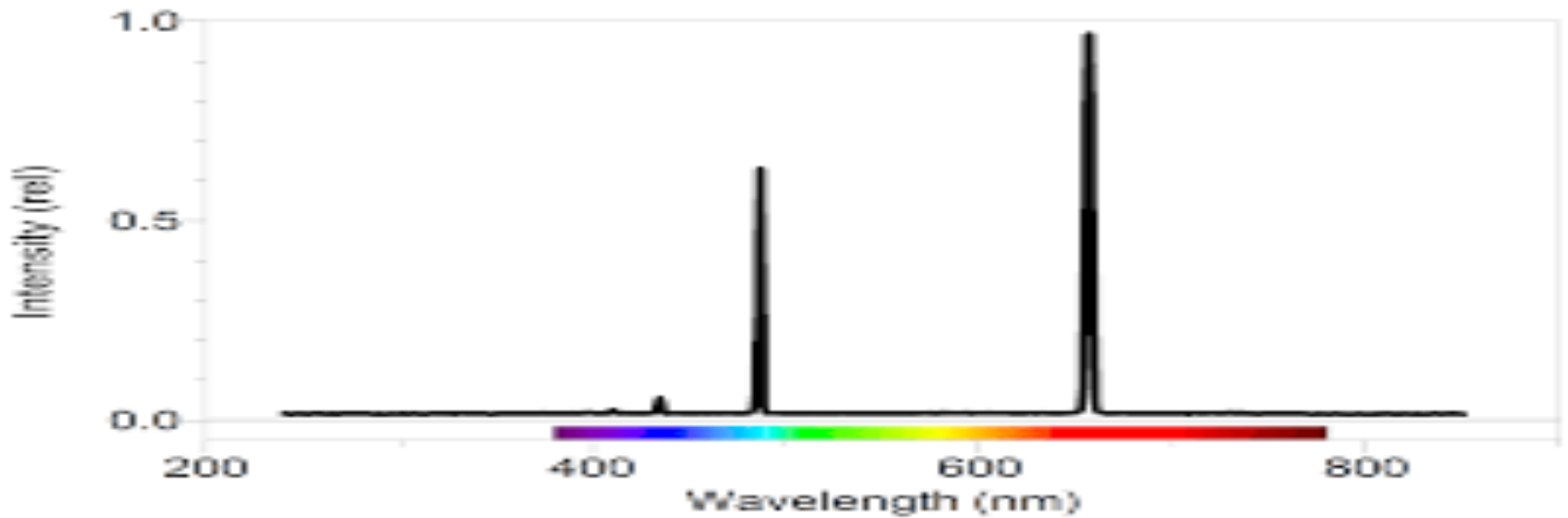
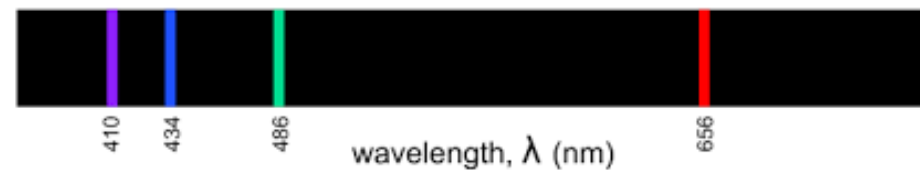
λ = wavelength (in meters) of emitted or absorbed photon

Energy level diagram for hydrogen:



Worksheet#7. Sketch the spectrum for Hydrogen in visible

Hydrogen Emission Spectrum



Ionization

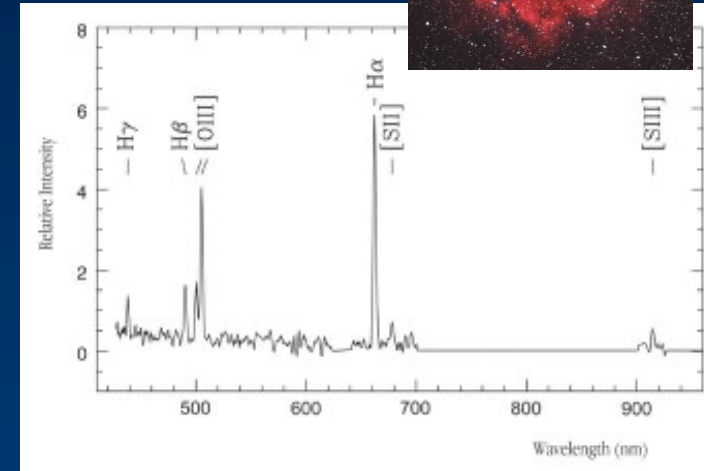
- If an atom or a molecule absorbs enough energy from a photon or a collision, an electron can escape the nuclear attraction => positive ion. For H, takes at least a 13.6 eV photon.
- By adding electrons, you can get a negative ion
- Each ion has its own energy levels
- “N II”, “N III”: N with one or two electrons removed. Takes higher energy photons to remove more electrons (e.g. O II: 13.6 eV, O III: 35 eV).

Fingerprints of matter

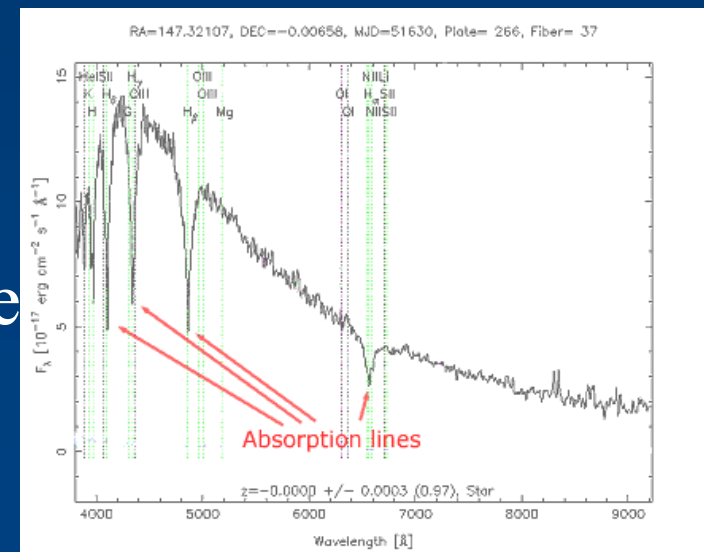
- Hydrogen has an easy orbital structure, but more complex atoms (several electrons) will have more complicated structure:
 - More energy levels and a more complex line spectrum
- Each element has a unique spectrum, reflecting the unique electron orbital structure
- Isotopes have same lines, but slightly shifted in wavelength
- Geisler tubes

Emission and absorption line spectra

- Hot, low density gas, where collisions between atoms have sufficient energy to cause electrons to move to higher levels, gives emission lines. Also gas around very hot, young stars becomes ionized, and produces emission lines as it recombines.

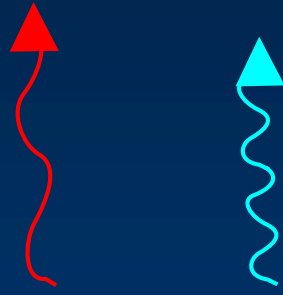
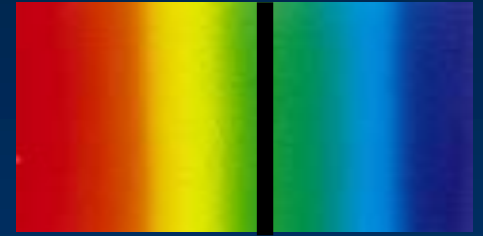


- Light from continuous spectrum through cooler gas gives absorption lines, as absorbed photons cause electrons to move to higher levels. Re-emitted photons are in random direction, so incident light in original direction much reduced.



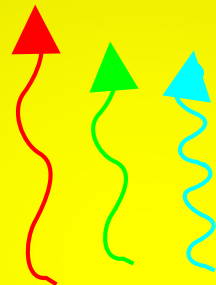
So why do stars have absorption line spectra?

Simple case: let's say these atoms can only absorb green photons. Get dark absorption line at green part of spectrum.



“atmosphere” (thousands of K) has atoms and ions with bound electrons

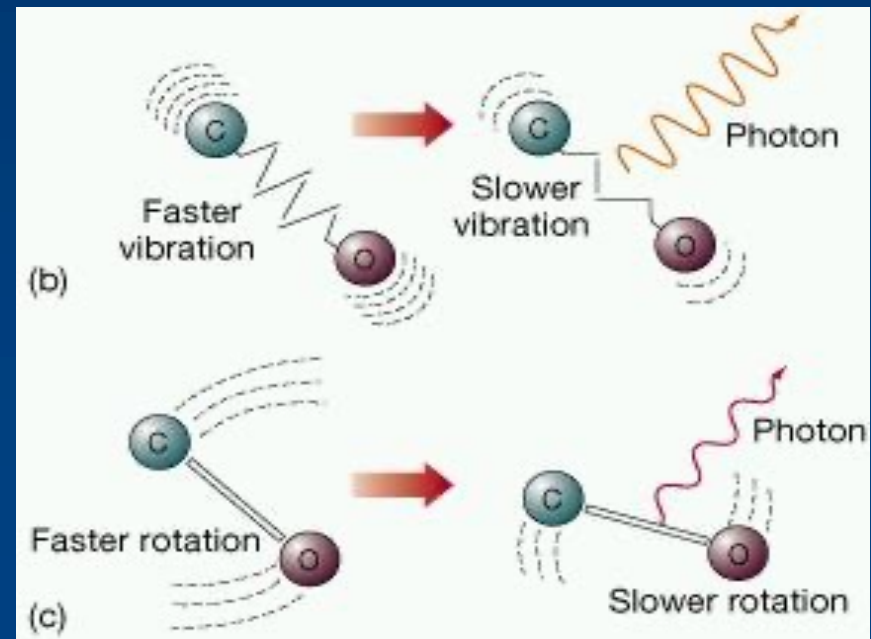
hot (millions of K), dense interior has blackbody spectrum, gas fully ionized



Molecules

- Even more complex - compounds of two or more atoms of same or different elements
- Share some electrons in common orbitals
- Have vibrational and rotational energy levels as well (IR, microwave, radio)

=> Very complex spectra!



Kirchhoff's Laws

1. A hot, opaque body, or a hot, dense gas produces a **continuous spectrum**.

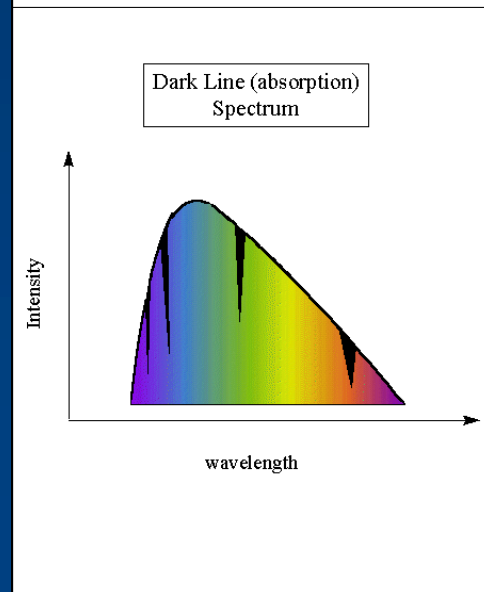
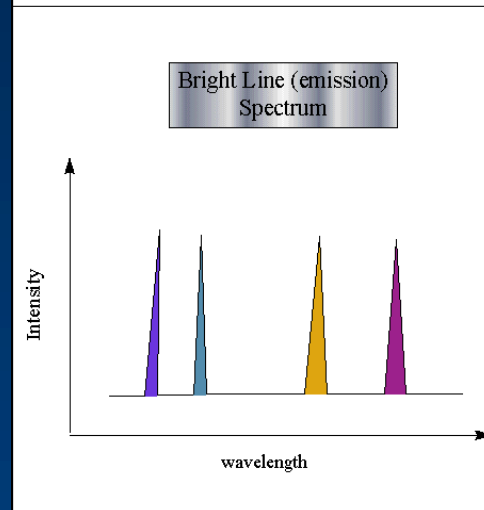
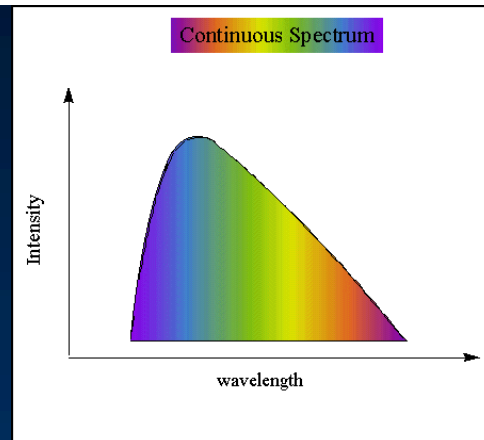
Explained

2. A hot, transparent gas produces an **emission line spectrum**.

Explained

3. A cool, transparent gas in front of a source of a continuous spectrum produces an **absorption line spectrum**.

Explained



Spectroscopy

The spectrum of an objects tells us:

- Which atoms and molecules are present, and in which proportions
- Which atoms are ionized, and in which proportions
- How excited the atoms are, which tells us about the physical state (cold, hot)
- Motion of the object

⇒ Spectroscopy is a very important tool of the astronomer! (invented by Gustaf Kirchoff)

(Particles emit and absorb photons in other ways, too. We'll deal with those processes as needed.)

What is brightness?

- We need to be able to quantify how bright an object is
- Wave picture: brightness corresponds to amplitude
- Particle picture: brightness corresponds to the number of photons per second from the source

The particle picture turns out to be more useful for expressing brightness.

Fundamental forces of nature

Interactions in nature are governed by four fundamental forces:

1. Gravitational force
2. Electromagnetic force
3. Strong nuclear force
4. Weak nuclear force

The interplay of forces

- Gravity dominates on largest scales: binds massive objects together, and mediates orbital motions
- Electromagnetism dominates on atomic scale: binds electrons to protons, atoms to molecules
- Strong and weak forces dominates on nuclear scales: binds protons to neutrons, mediates nuclear reactions

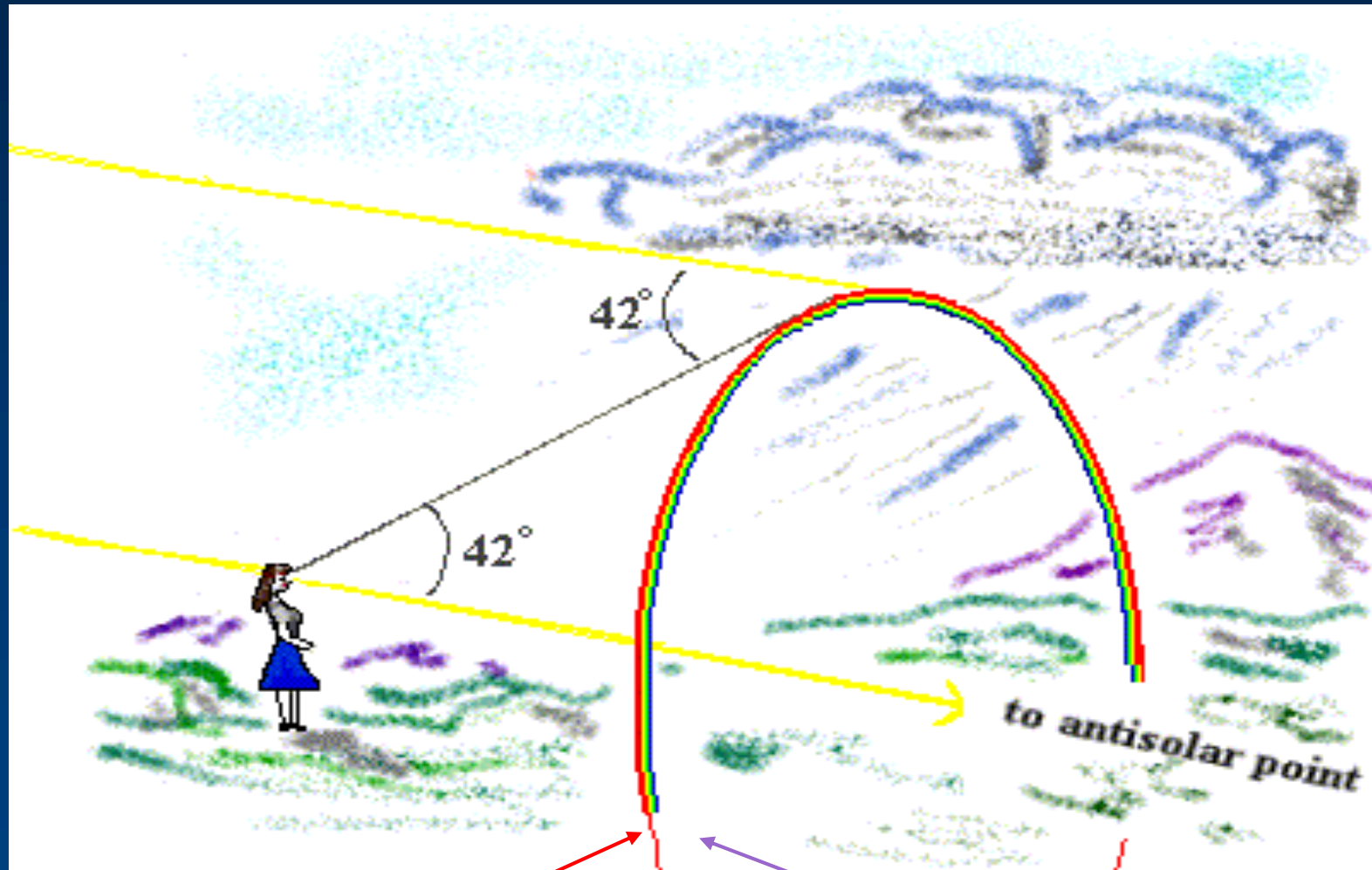
Rainbows



Rainbows

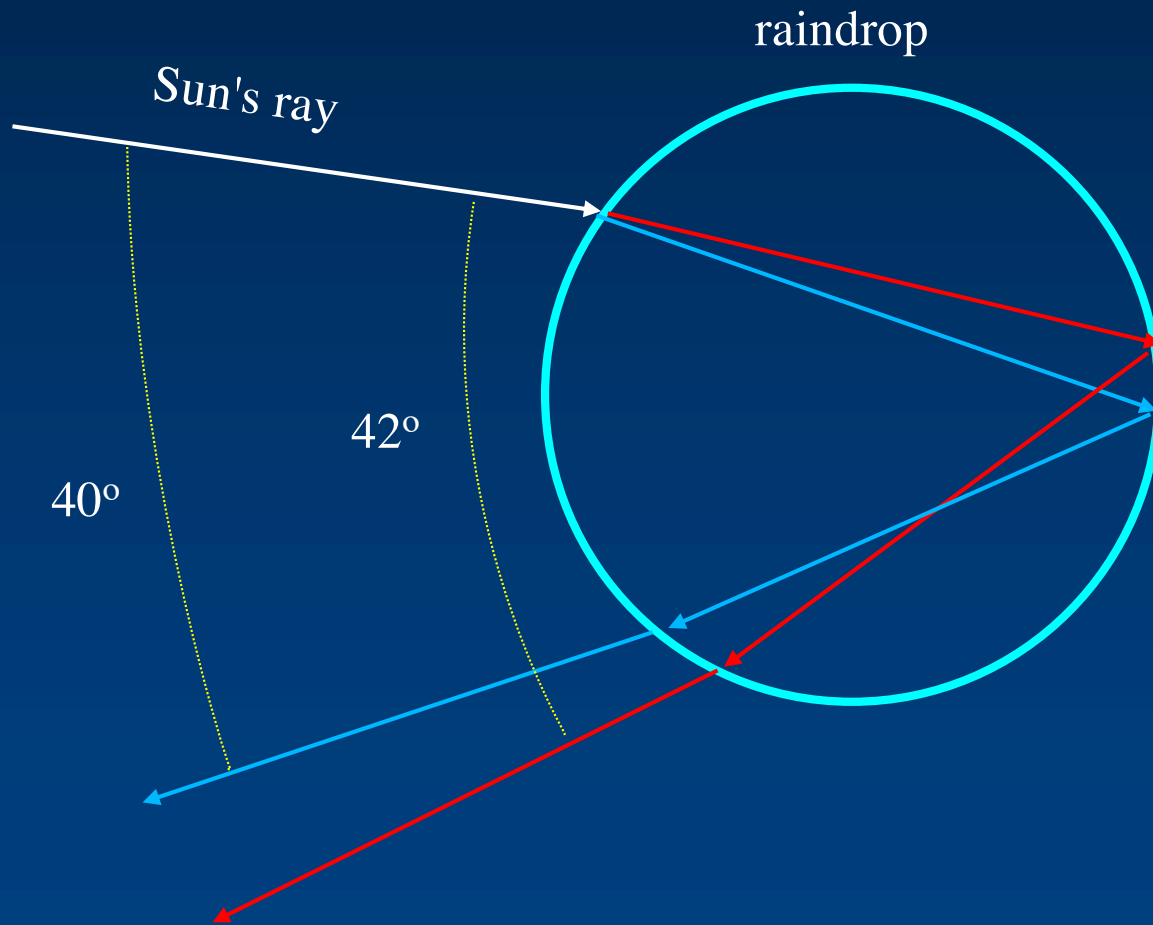


Rainbows

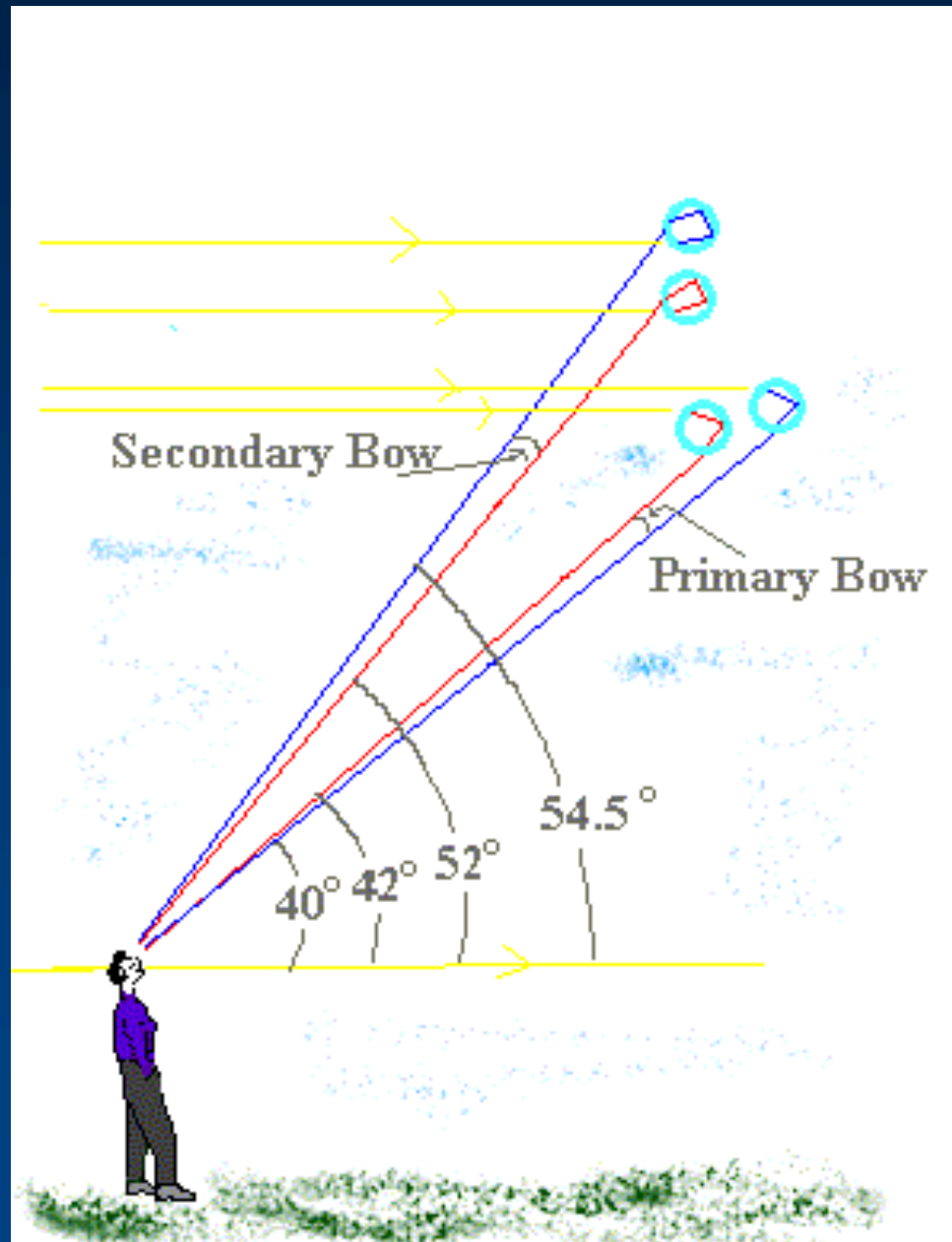


red orange yellow green blue violet

What's happening in the cloud?



Double Rainbows

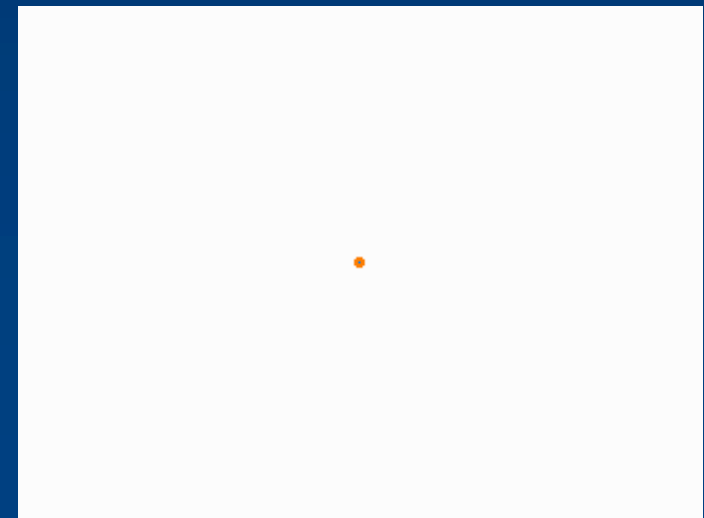
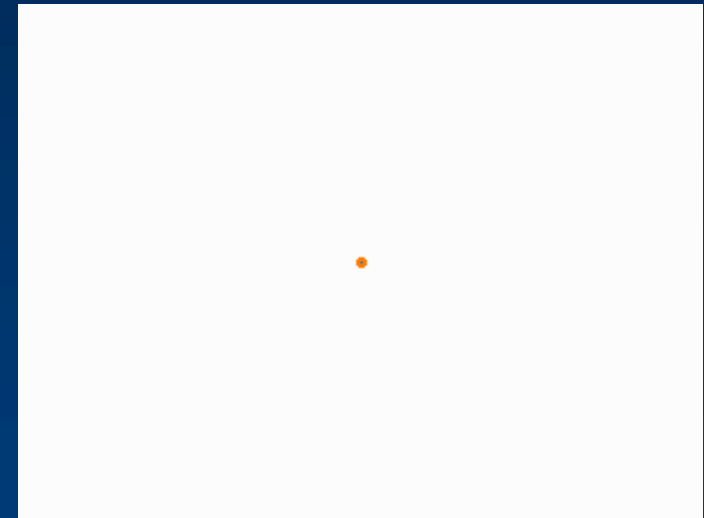
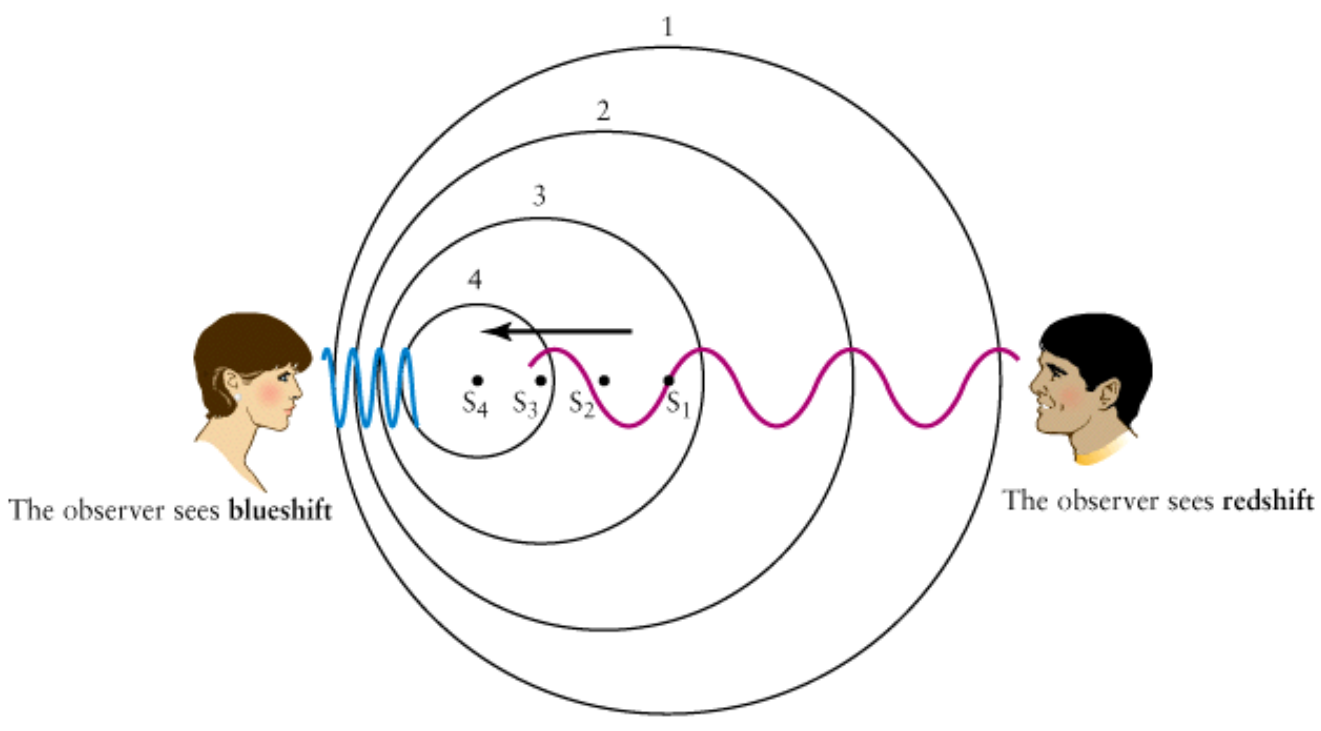


Sun Dogs and Crazy Clouds



The Doppler shift

Frequency or wavelength of a wave depends on relative motion of emitter and receiver (along the direction of wave motion).

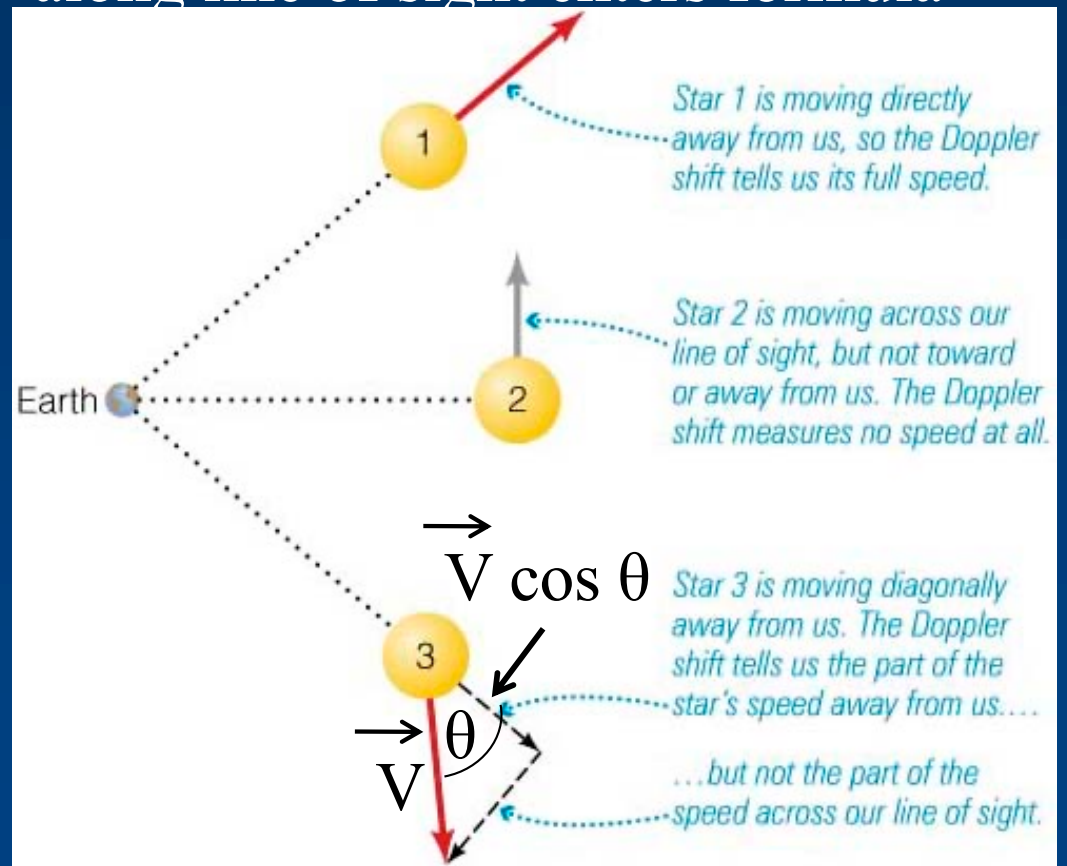
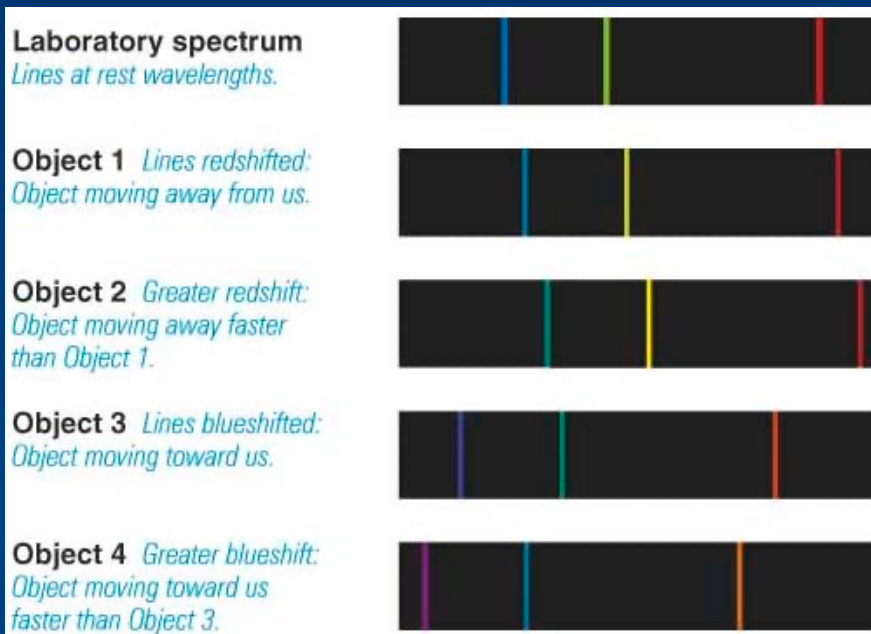


$$V = \frac{\lambda_{observed} - \lambda_{emitted}}{\lambda_{emitted}} c = \frac{\Delta\lambda}{\lambda_{emitted}} c$$

where V is the relative velocity along the line of sight, and c is the speed of light (both in same units, e.g. m/s).

If V is at some angle, only component along line of sight enters formula

Spectral lines are used to measure Doppler shift => gives us information about the motion of an object.



Example Doppler shift

- A spectral line normally seen at 300nm is shifted to 301nm due to relative motion of the source. What is the velocity of the source? Is it approaching or receding? “Redshift” or “blueshift”?
- What is the velocity?