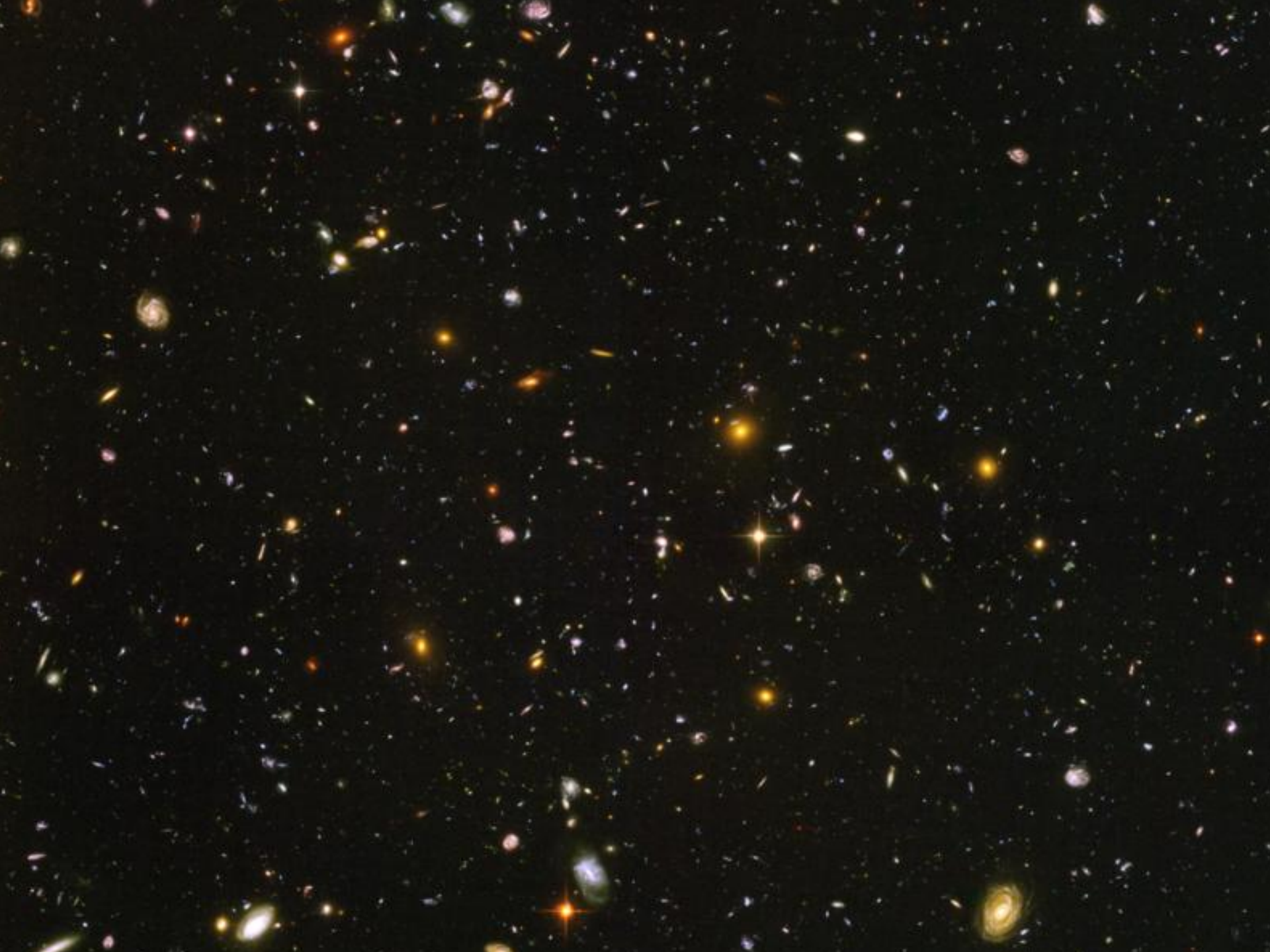
www.astro.yale.edu/astro120

Prof. Jeff Kenney

Class 5

June 1, 2018



to understand how we know stuff about the universe we need to understand:

1. the spectral analysis of light

2. how light interacts with atoms & molecules

Refraction & dispersion of light & making a spectrum

Refraction: light rays bends when they pass from one medium to another; e.g. air to glass, or space to atmosphere

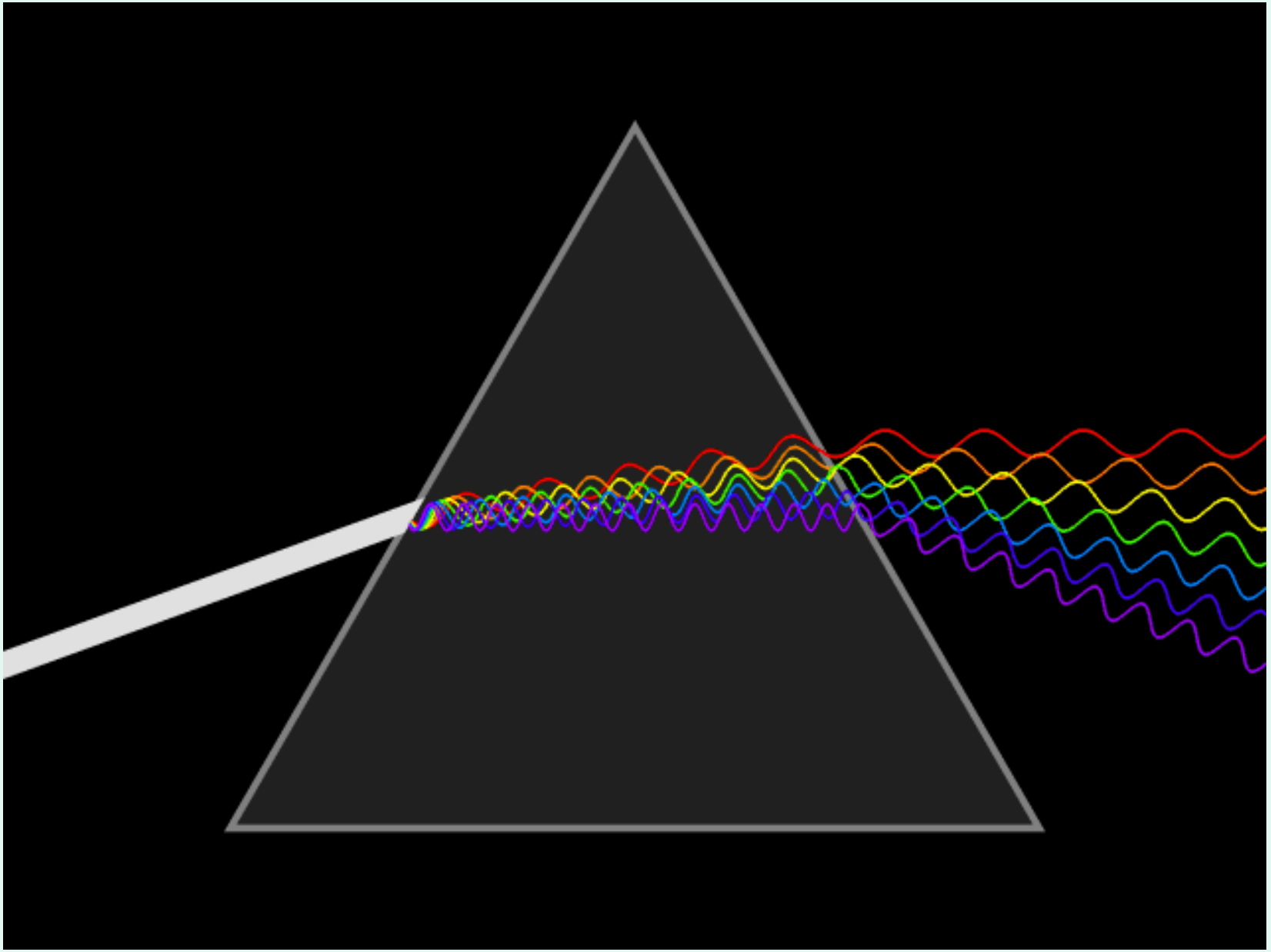
Refraction & dispersion of light & making a spectrum

Refraction: light rays bends when they pass from one medium to another; e.g. air to glass, or space to atmosphere

Dispersion = Differential Refraction: different colors (wavelengths) refracted by different amounts

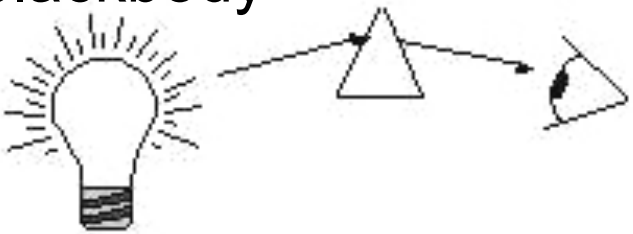
The constituent colors (wavelengths) of (white) light get spread out (refracted by different angles) by prism (or other refracting element, e.g. diffraction grating)

This happens because the speed of light is different in different media. e.g. slower in glass, & blue slows down more than red. Bending can be understood thru the wave description of light

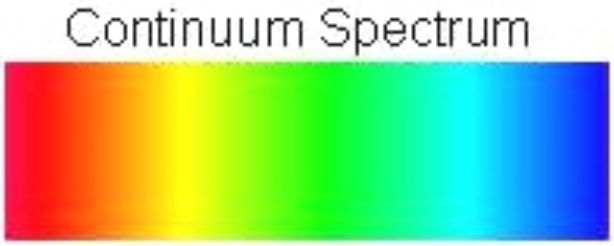


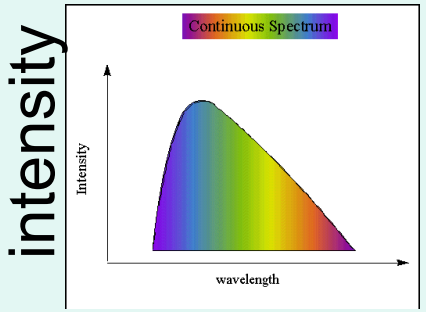
Kirchoff's laws

blackbody



opaque



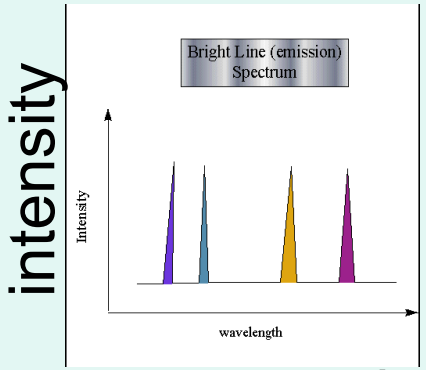


intensity

wavelength

Kirchoff's laws

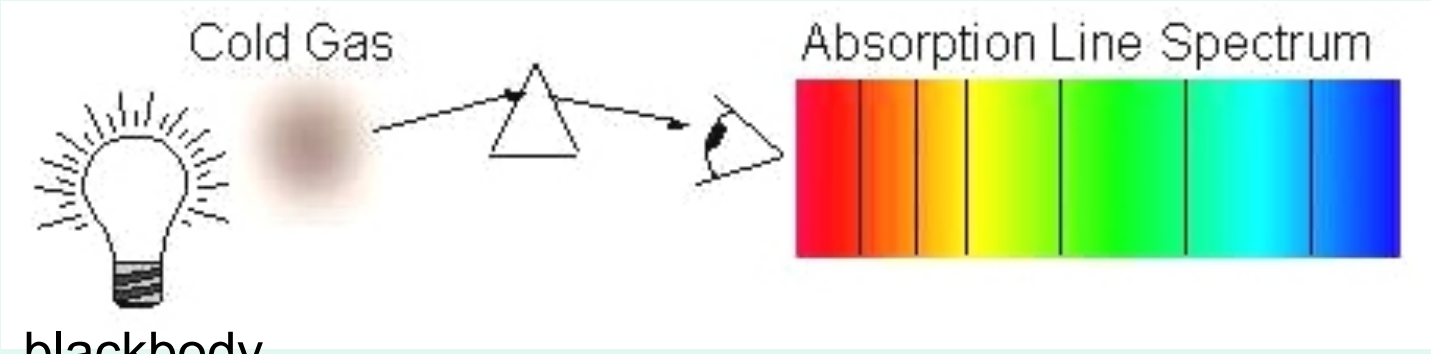
transparent/
translucent



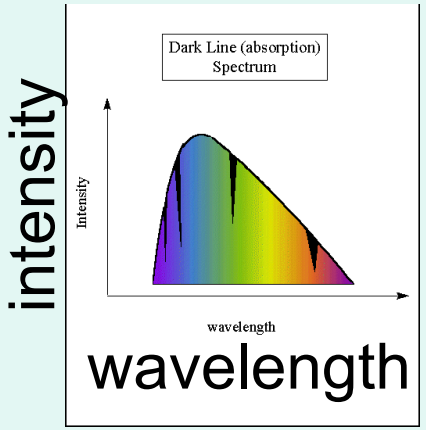
intensity

wavelength

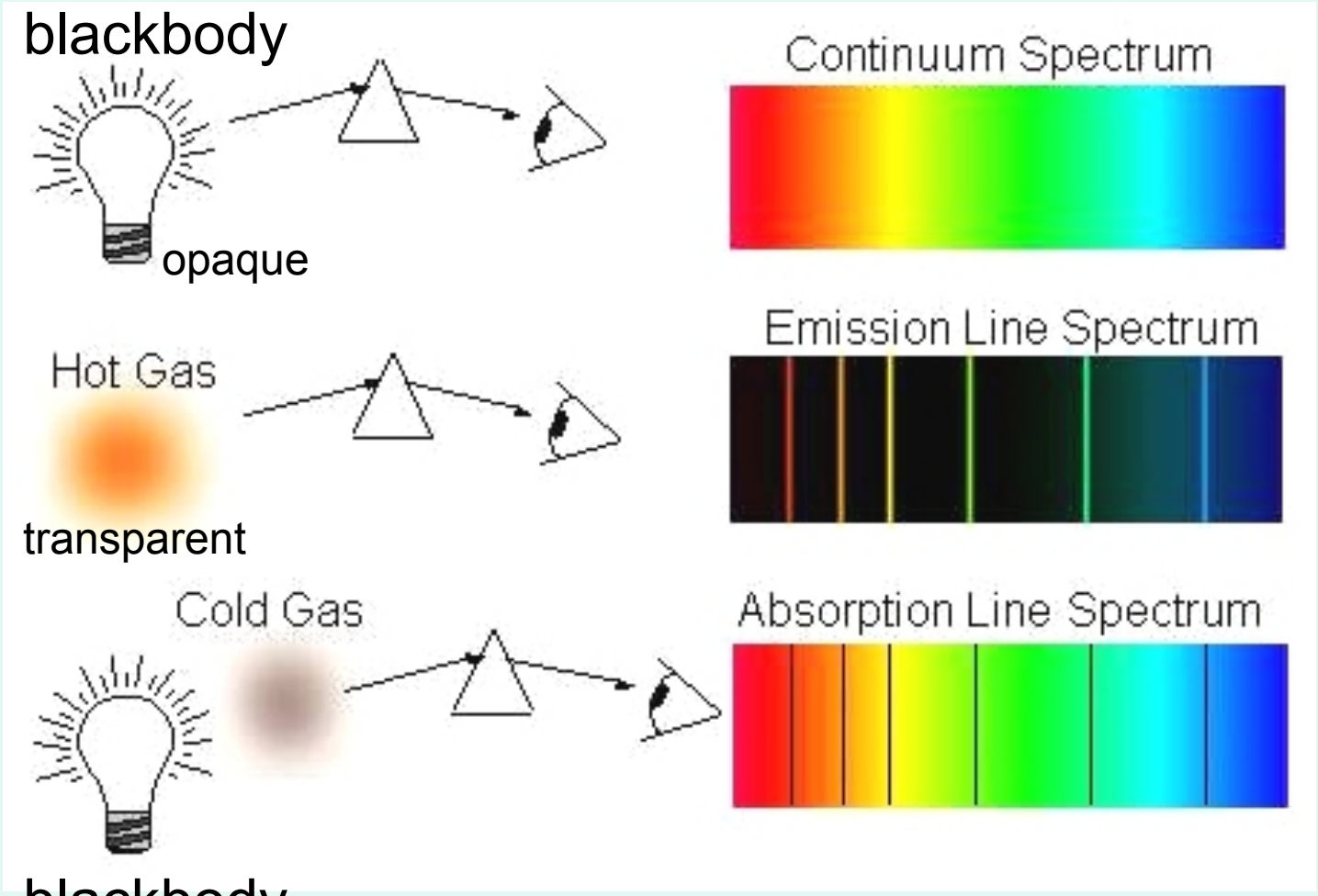
Kirchoff's laws



blackbody
opaque
(hotter than
the "cold gas")



Kirchoff's laws



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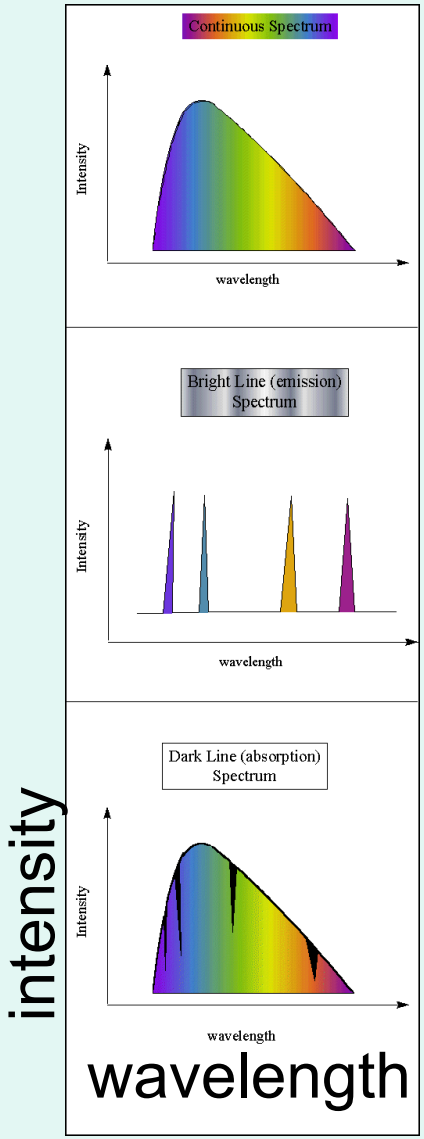


Suppose Alex and Andrea look at the spectrum of the same gas cloud in a laboratory. Alex sees emission lines and Andrea sees absorption lines. How can this be?

A. Andrea sees the gas against a hot background

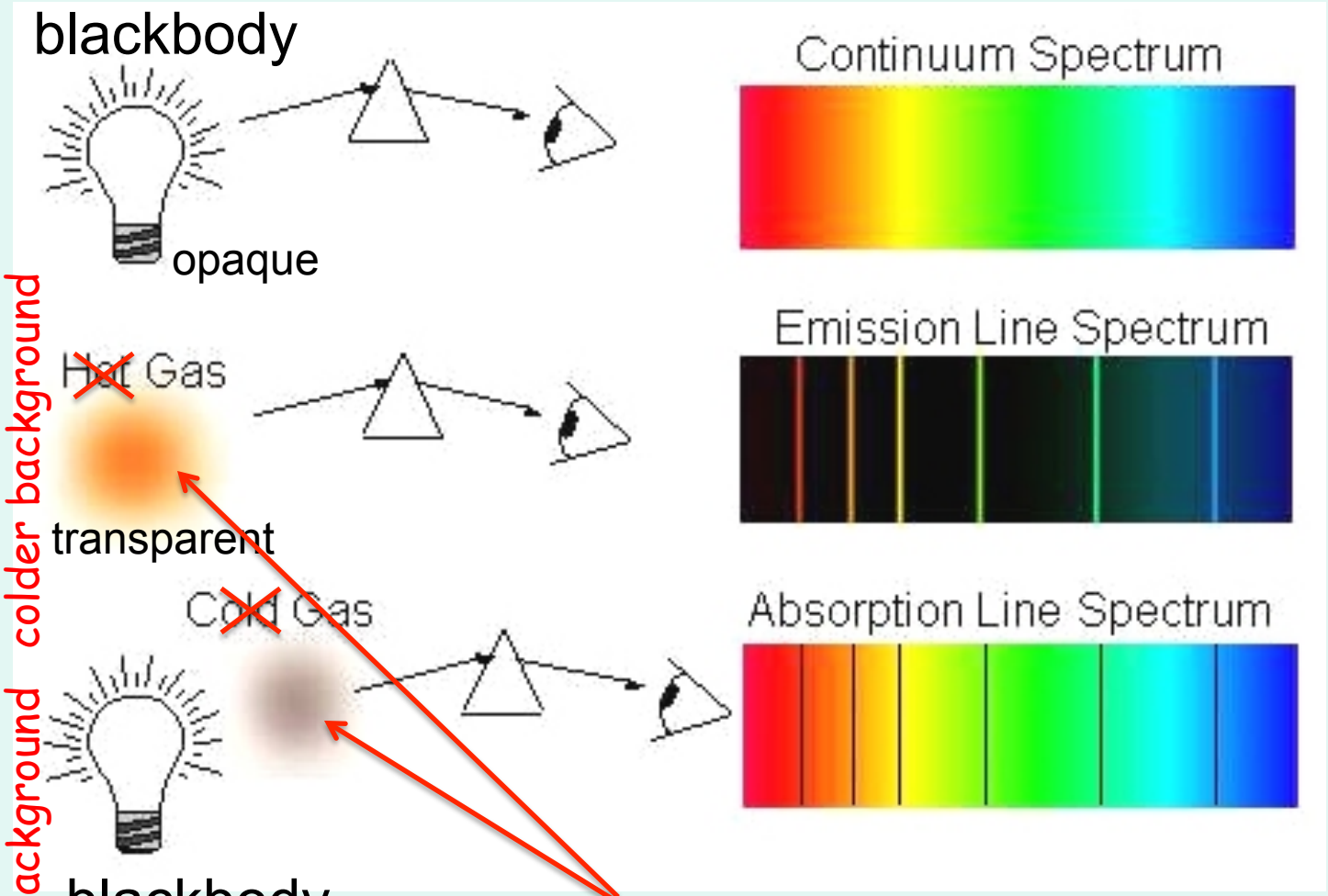
B. Andrea sees the gas against a cold background

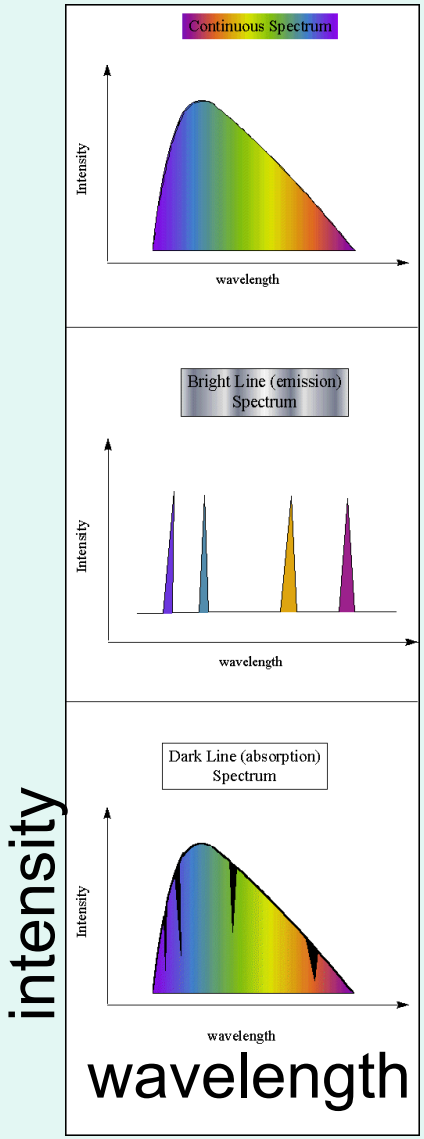
C. Alex sees the gas against a hot background

D. Alex sees the gas against a cold background

E. Alex is hotter than the gas cloud

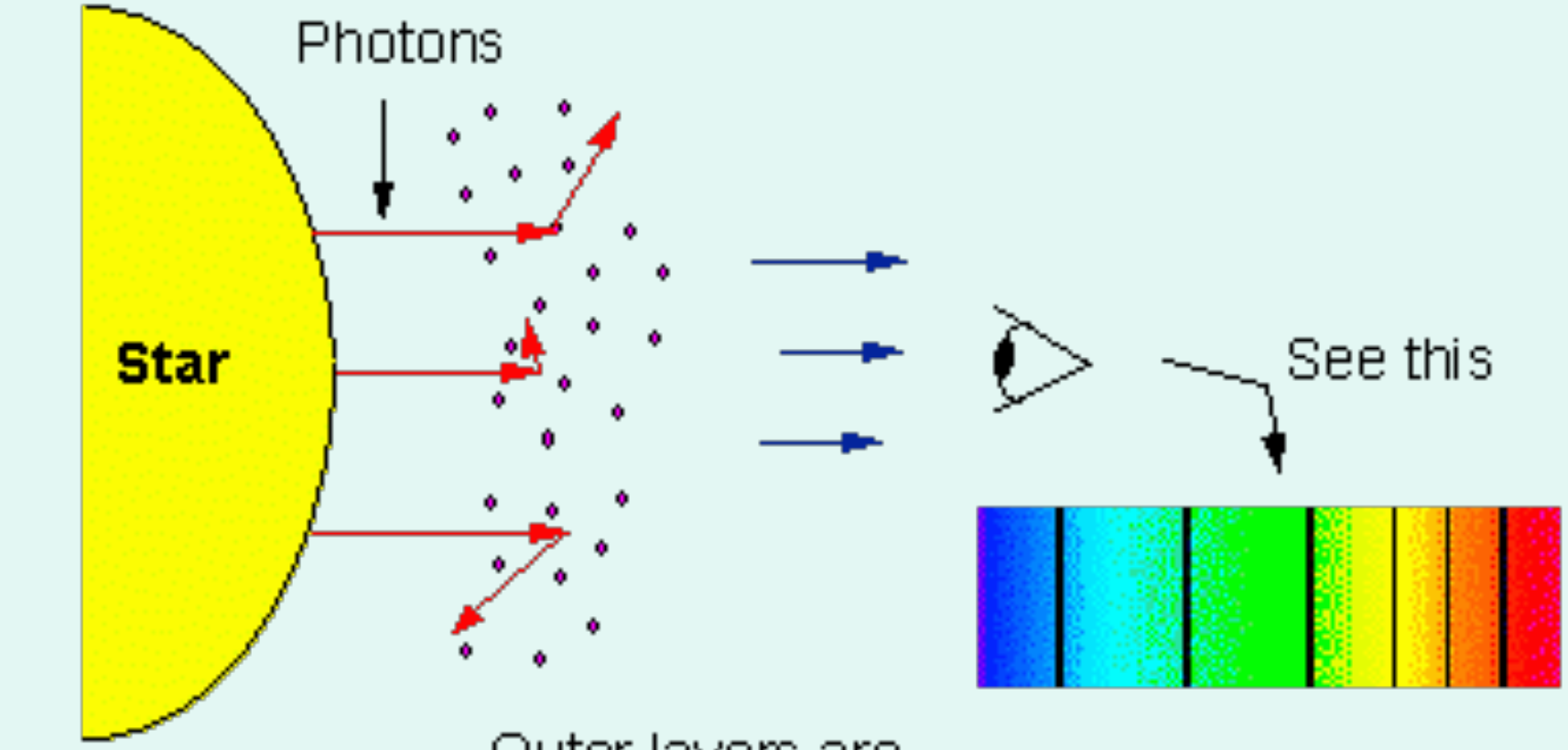
Kirchoff's laws





these gas clouds could be at same temperature! difference is whether something hotter or colder is behind translucent gas cloud

Why does sun have absorption line spectrum?



What makes spectral lines?

- Emission or absorption lines arise when atom or molecule changes its internal energy, from one state to another, *by emitting or absorbing a photon*

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What makes spectral lines?

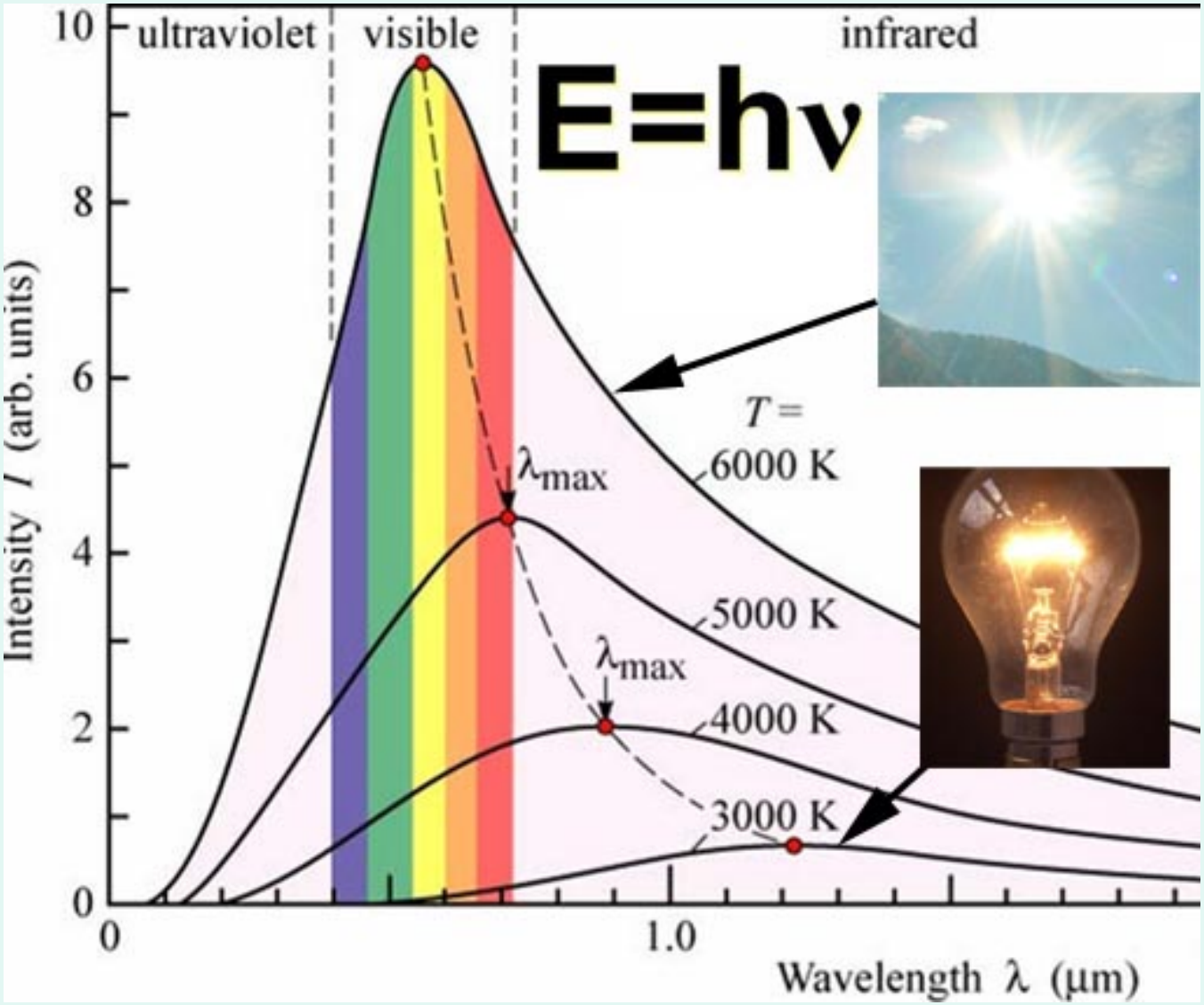
- Emission or absorption lines arise when atom or molecule changes its internal energy, from one state to another, *by emitting or absorbing a photon*
- *Energy levels are quantized (discrete, not continuous)*
- *Every atom and molecule has its own unique set of spectral lines*

Continuum light source in demo

- Incandescent electric light bulb with filament surrounded by vacuum
- Electric current runs through filament, which heats up to ~2000-3000K
- Filament emits *roughly like a blackbody*, so see a continuous spectrum (full rainbow)
- Use (e.g.) tungsten for filament, since it has high melting point

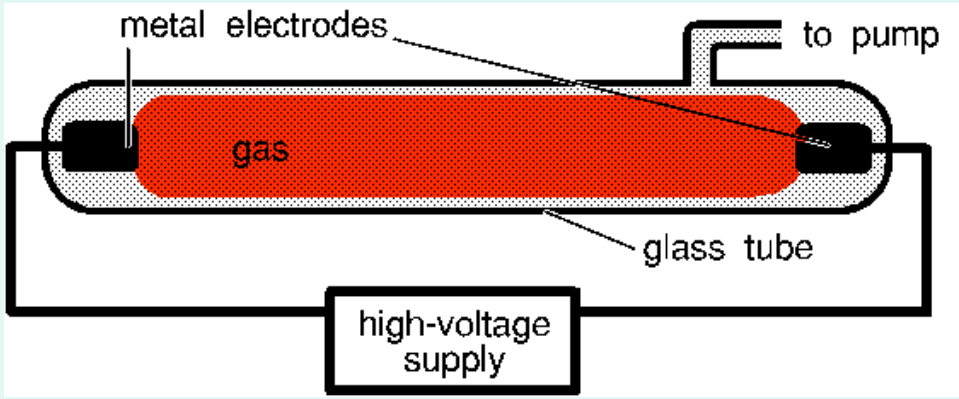
In which part of spectrum does the intensity peak?

Blackbody spectra of incandescent bulb & Sun



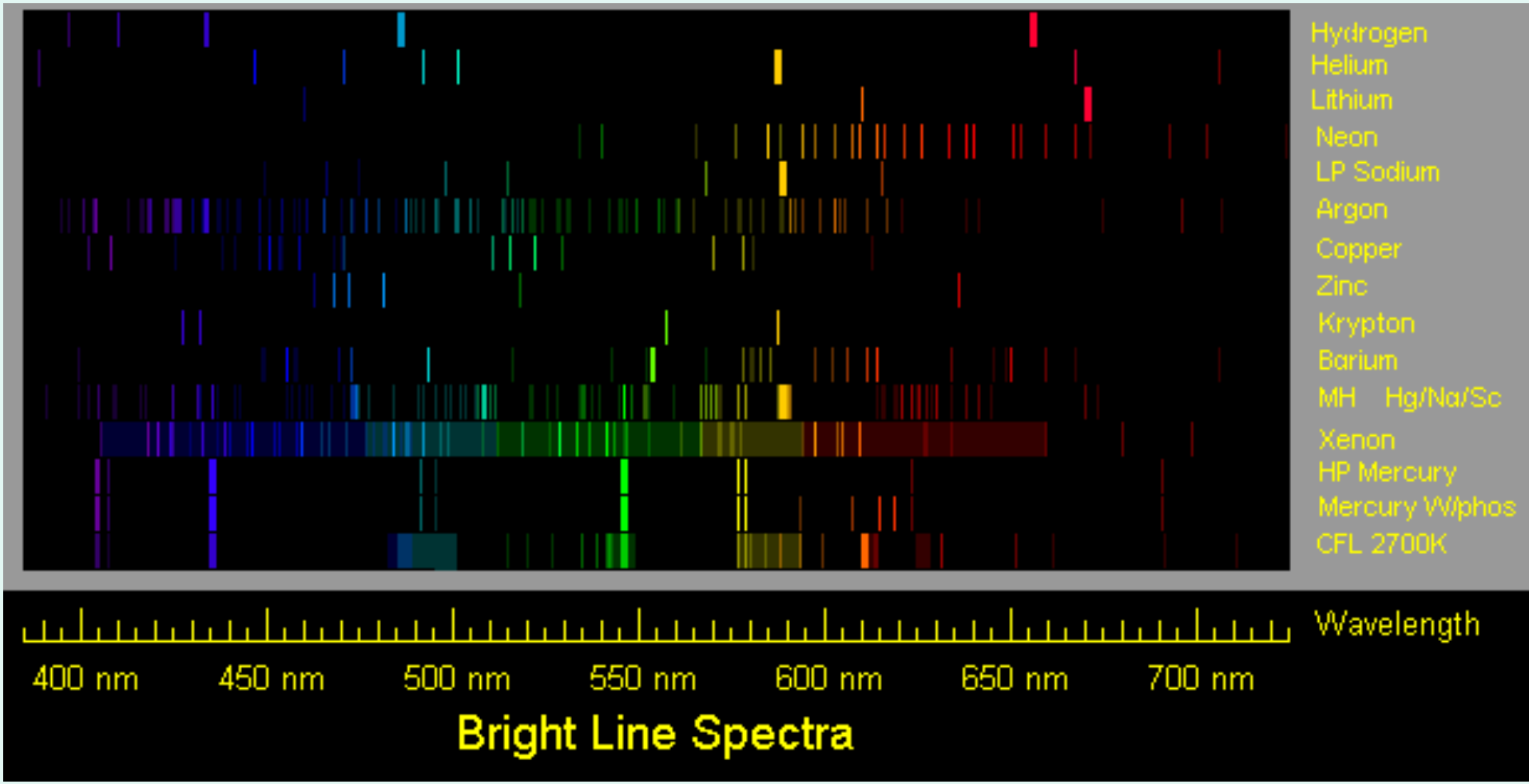
Most EM radiation from 3000K bulb in the infrared – only a little in the visible!

Emission line source in demo

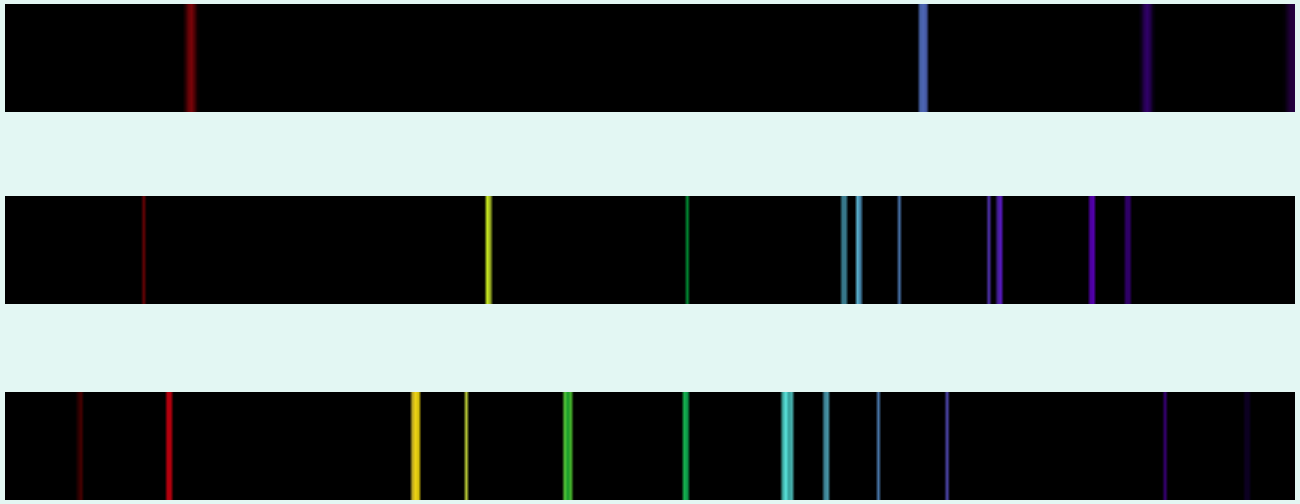


- Gas discharge tubes – gas of 1 atom or molecule – a heated, transparent gas
- Voltage applied across tube accelerates electrons, which crash into atoms, putting them into excited states
- See bright emission lines
- Each atom or molecule produces more than 1 line
- See unique pattern of lines for each different atom and molecule

Spectra of Different Elements



Spectra of Different Elements



Hydrogen

Helium

Carbon

Wavelength --->

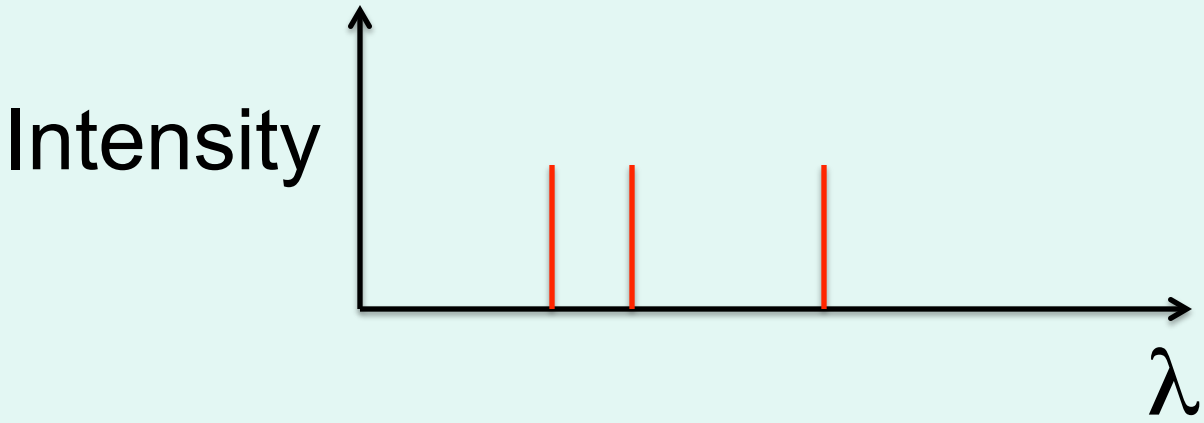
Spectral lines provide information on:

A. Which elements are present
B. The relative amounts of different elements
C. The temperature and density of the elements
D. The motions of the elements
E. All of the above

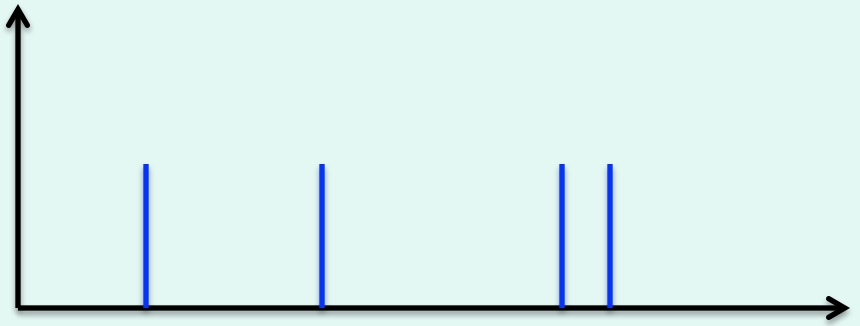
Importance of spectral lines in astrophysics – we can learn ALL THESE THINGS!!

1. Which elements are present (composition)
2. The relative amounts of different elements (abundances)
3. The temperature and density of the elements (physical conditions)
4. The motions of the elements (kinematics)

which elements are present

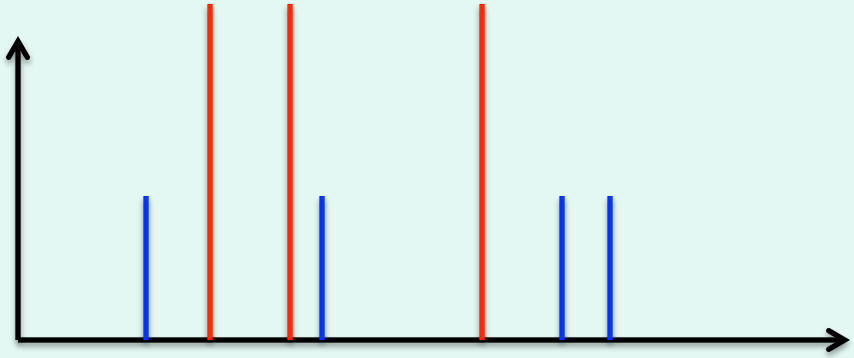


element
one (red)

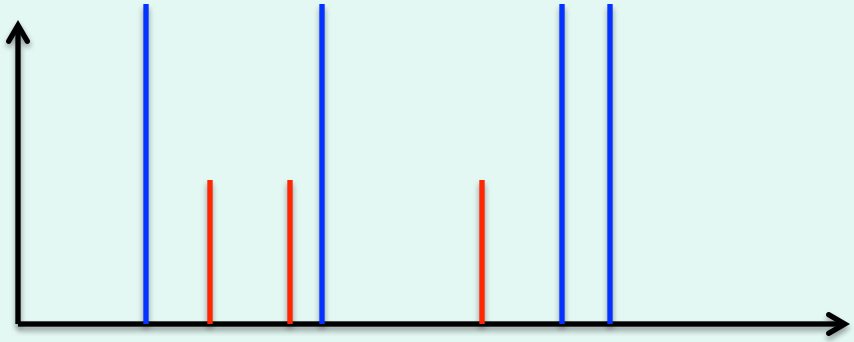


element
two (blue)

relative abundance of elements

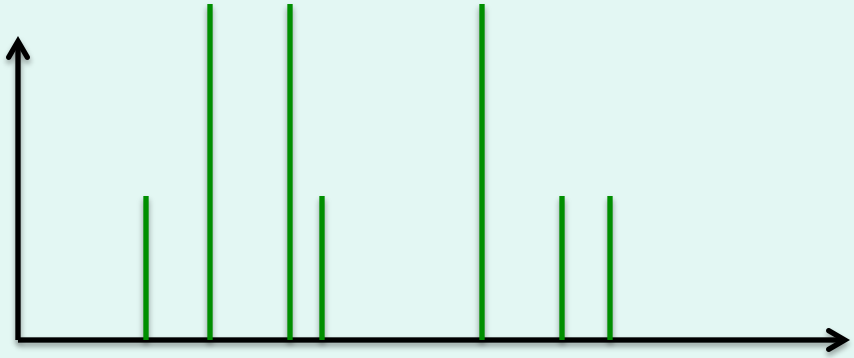


more of element one (red)

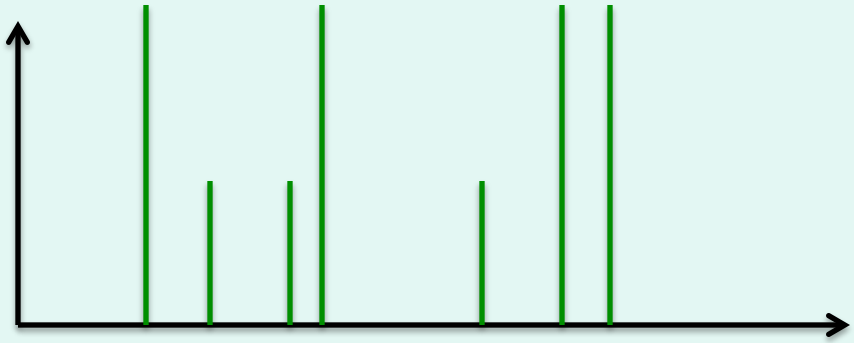


more of element two (blue)

relative abundance of elements

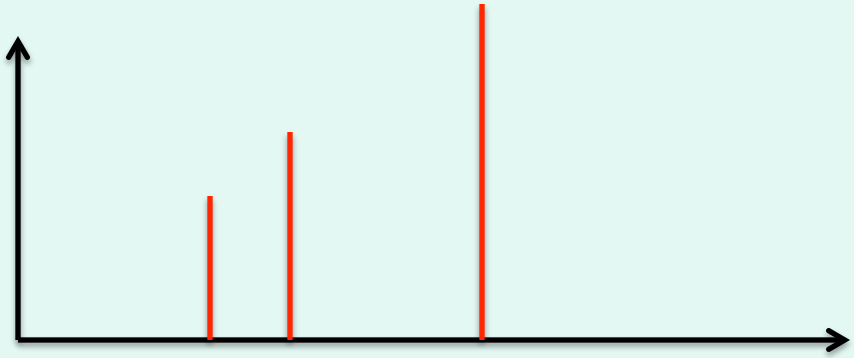


more of element one



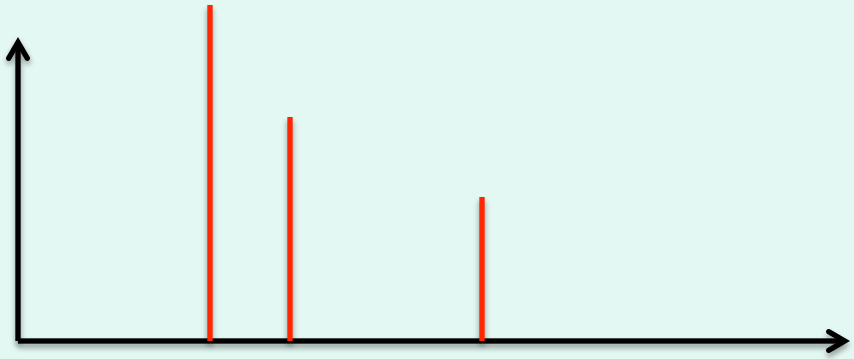
more of element two

physical conditions: temperature or density



element one:

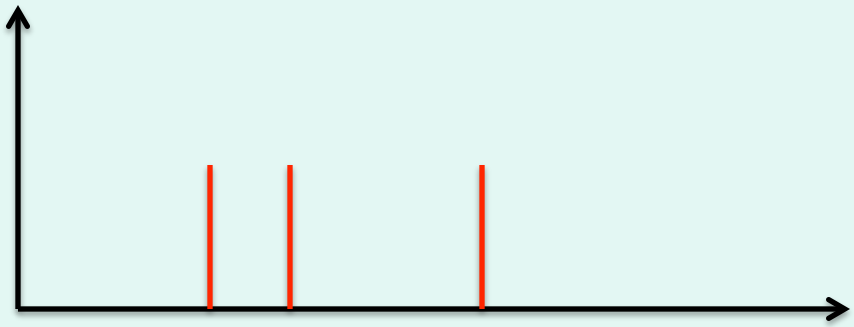
hotter gas



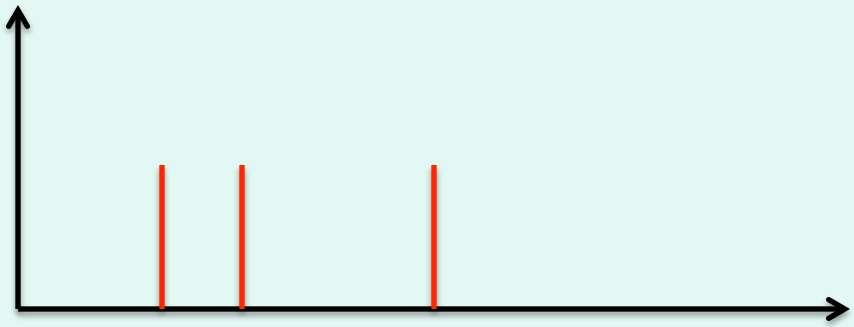
element one:

colder gas

motion



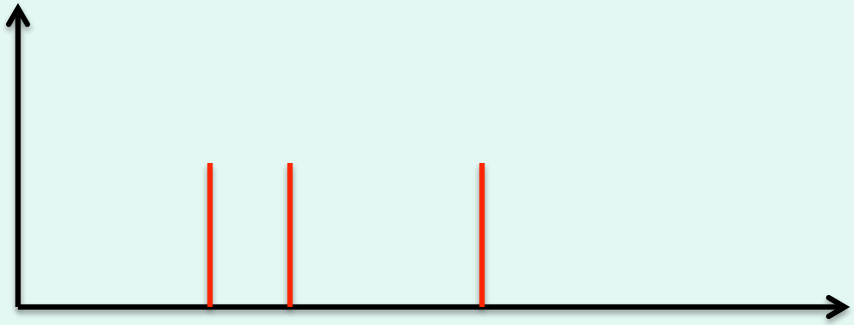
gas at rest



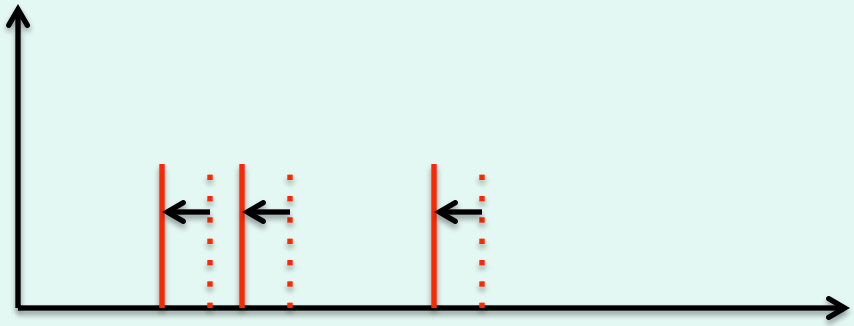
gas moving away

(doppler shifted)

motion



gas at rest



gas moving away

(doppler shifted)

Origin of Light

Where does light come from?

Need to know about atoms & molecules & ions & electrons, since they interact strongly with photons

They:

create/emit

destroy/absorb

redirect/scatter ….photons

atoms

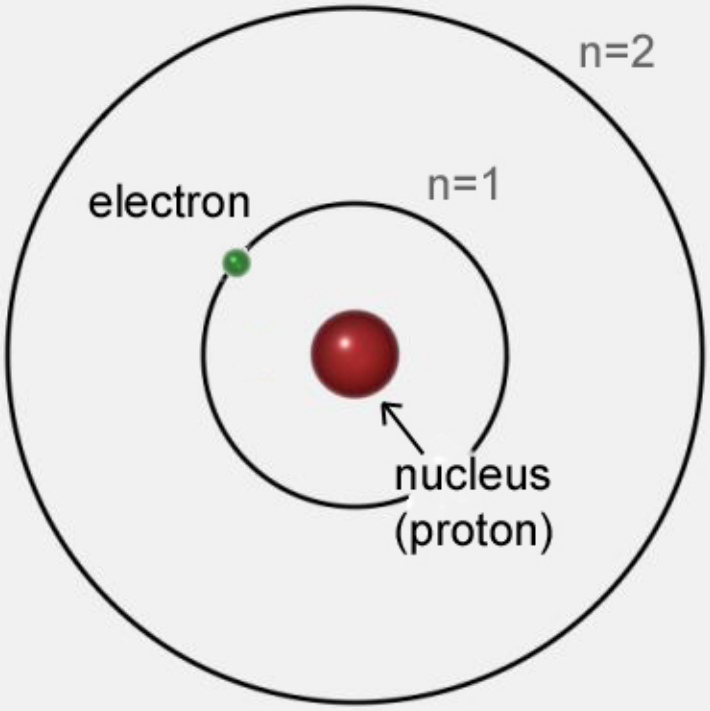
Structure determines:

A.) chemical properties

B.) light-emitting & absorbing properties

So understanding atoms (& other particles) is essential for understanding light from the universe

Bohr model of atom



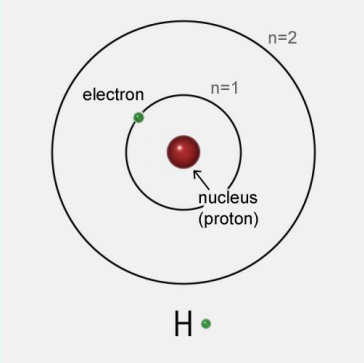
Nucleus contains:
Protons (+charge)
[Neutrons (no charge)]

Electrons (-charge)
in orbits around nucleus

p, e : equal & opposite electric charges
But very different masses!
$m_p = 1.673 \times 10^{-27}$ kg
$m_n = 1.675 \times 10^{-27}$ kg
$m_e = 9.109 \times 10^{-31}$ kg

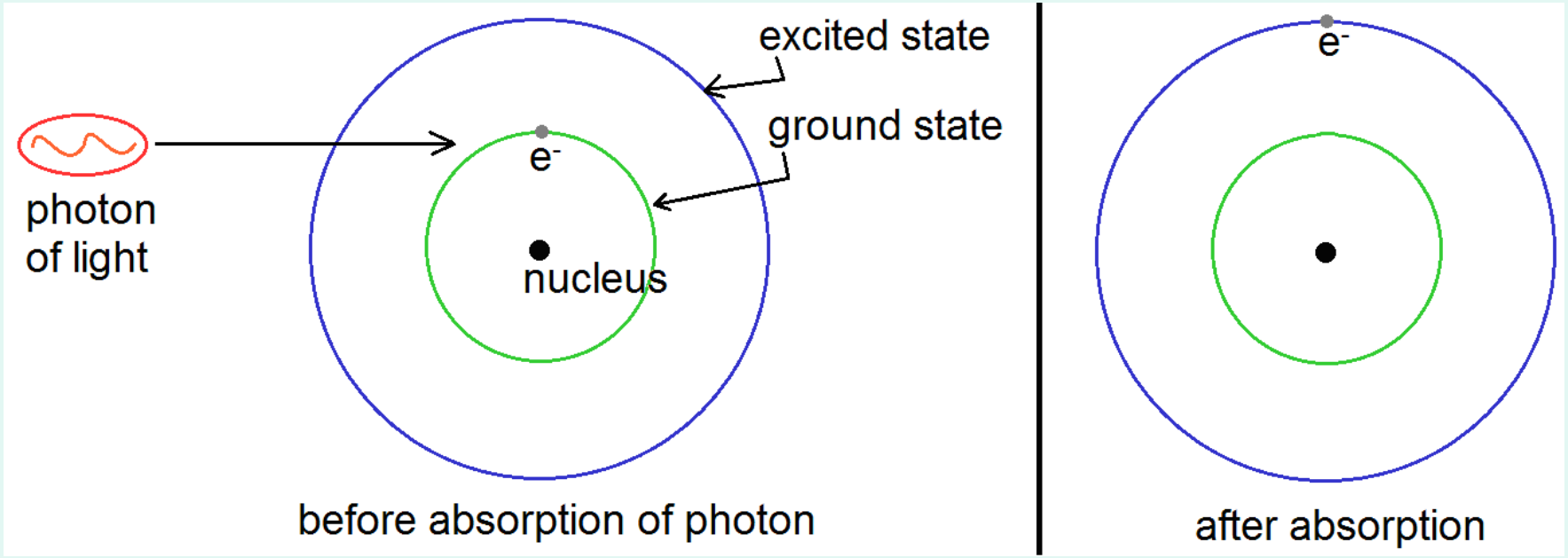
Electrons can't orbit at just any distance from nucleus, but only at certain discrete radii

Bohr model of atom



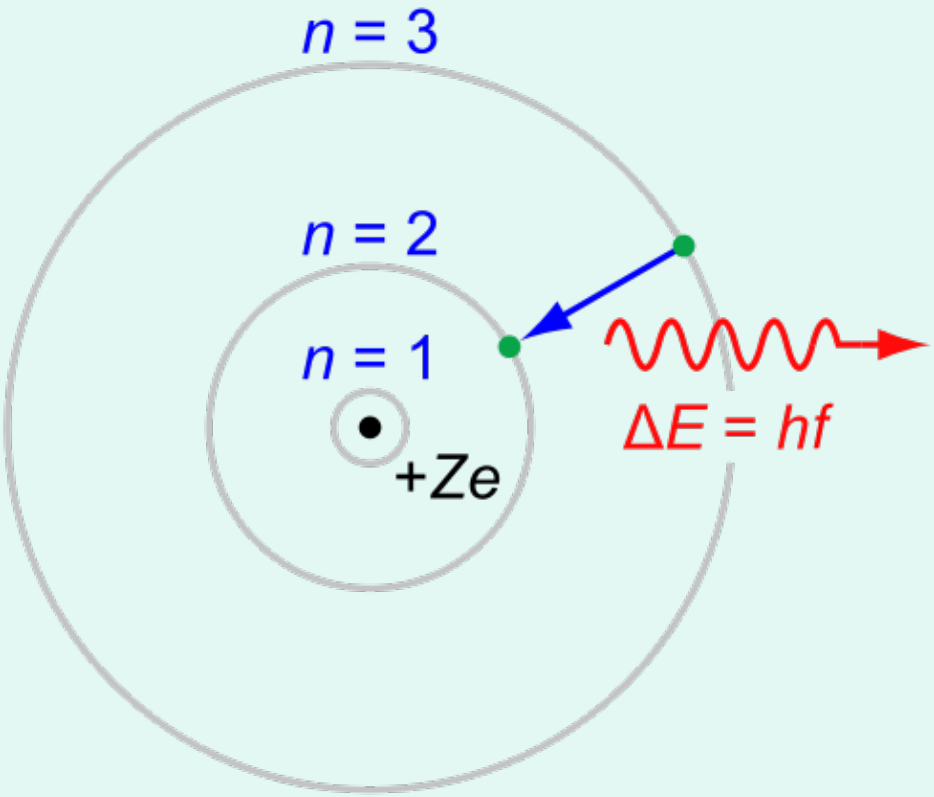
- *Electrons can't orbit at just any distance from nucleus, but only at certain discrete radii*
- Very different from planets!
- Kind of weird!
- Orbits are "quantized"
- Arises from wave-particle duality
- Each of possible orbits has certain energy associated with it
- Lowest energy level called the ground state

absorption

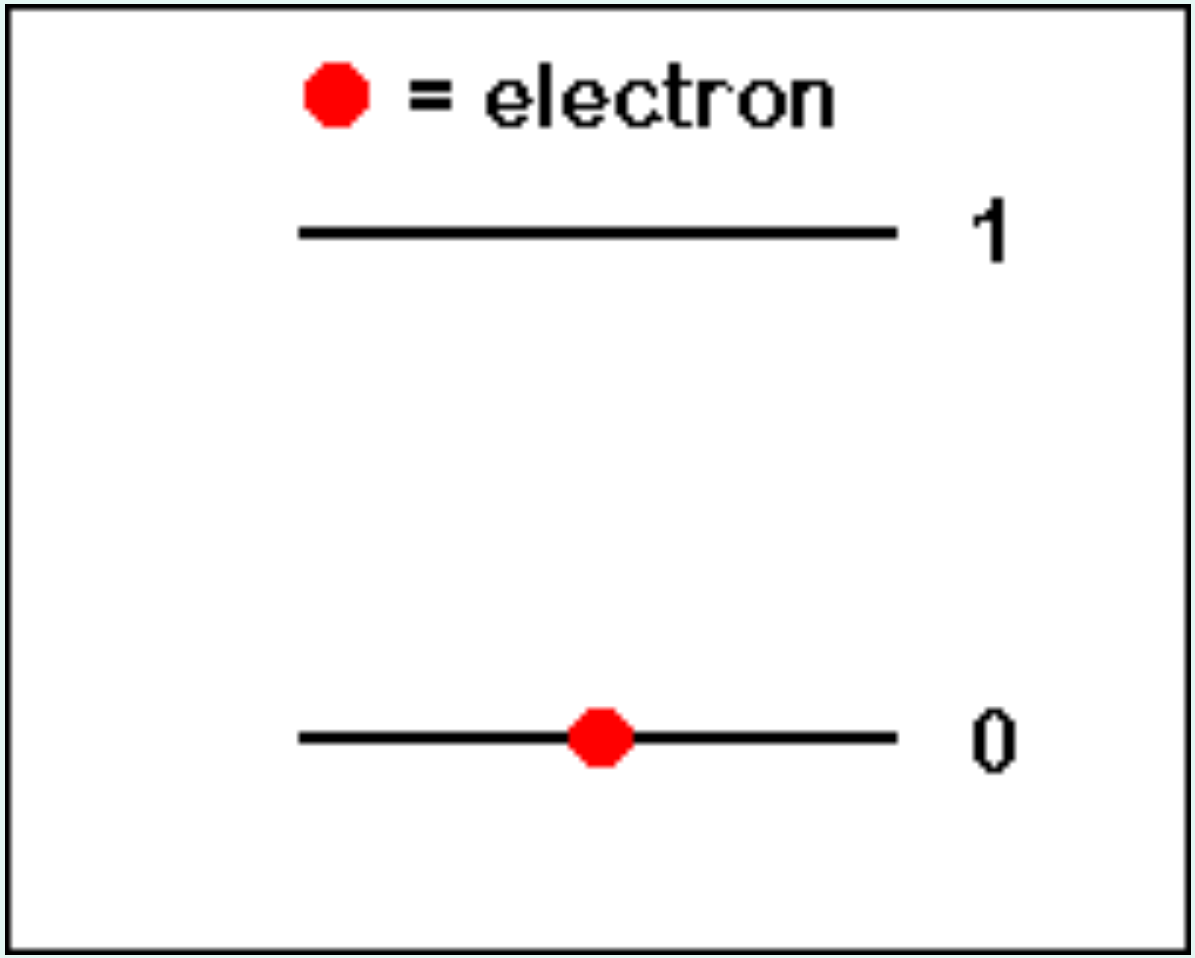


- An incoming photon which has an amount of energy ***exactly equal*** to the difference between 2 electronic energy levels will be absorbed
- Other photons (with "wrong" energy) will pass through without being absorbed

emission



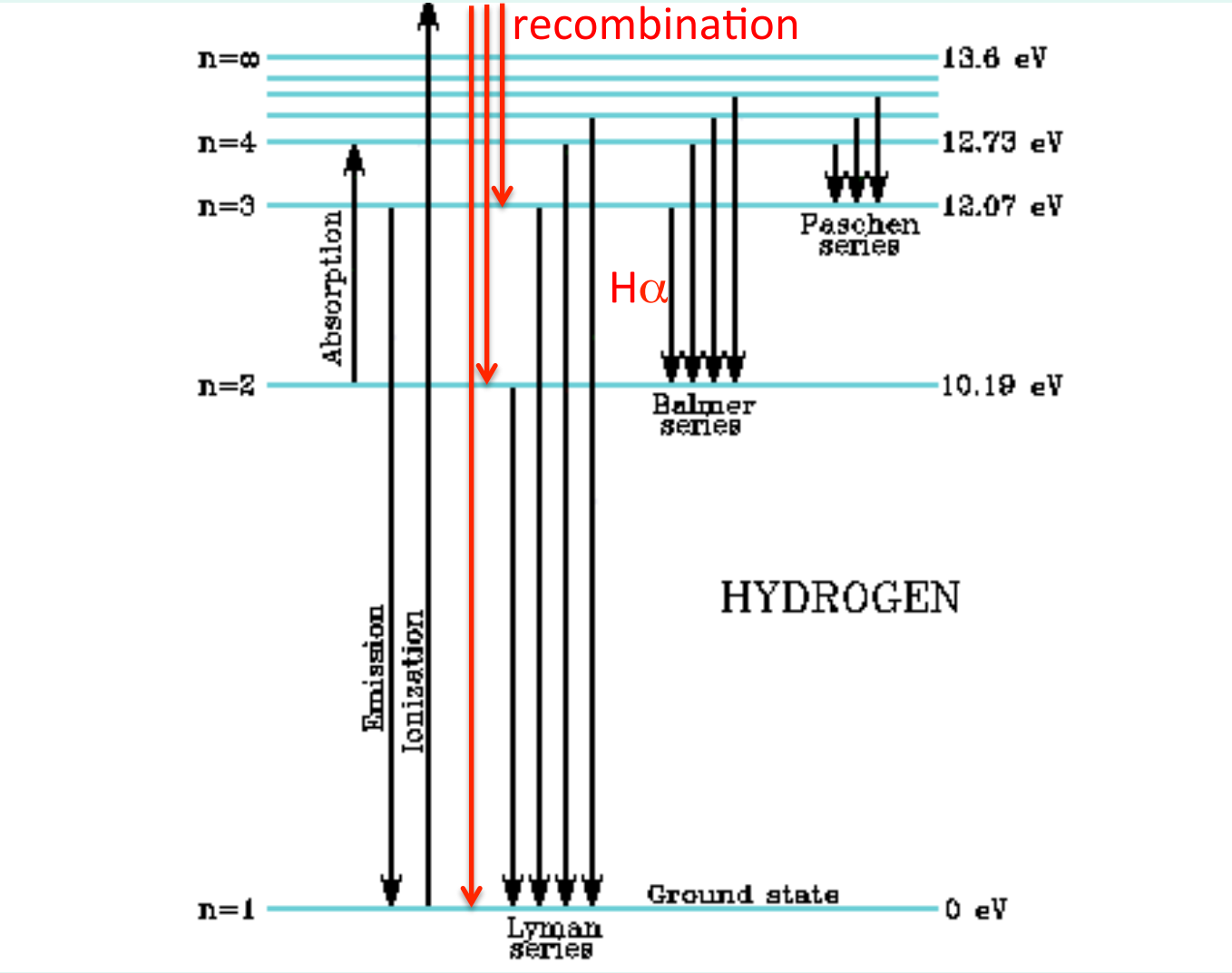
- Suppose H atom somehow gets excited (e.g., by collision with another atom, or if it previously absorbed a photon)
- After a while it will ***spontaneously*** fall to a lower energy level, emitting a photon as it does


= electron
1
0

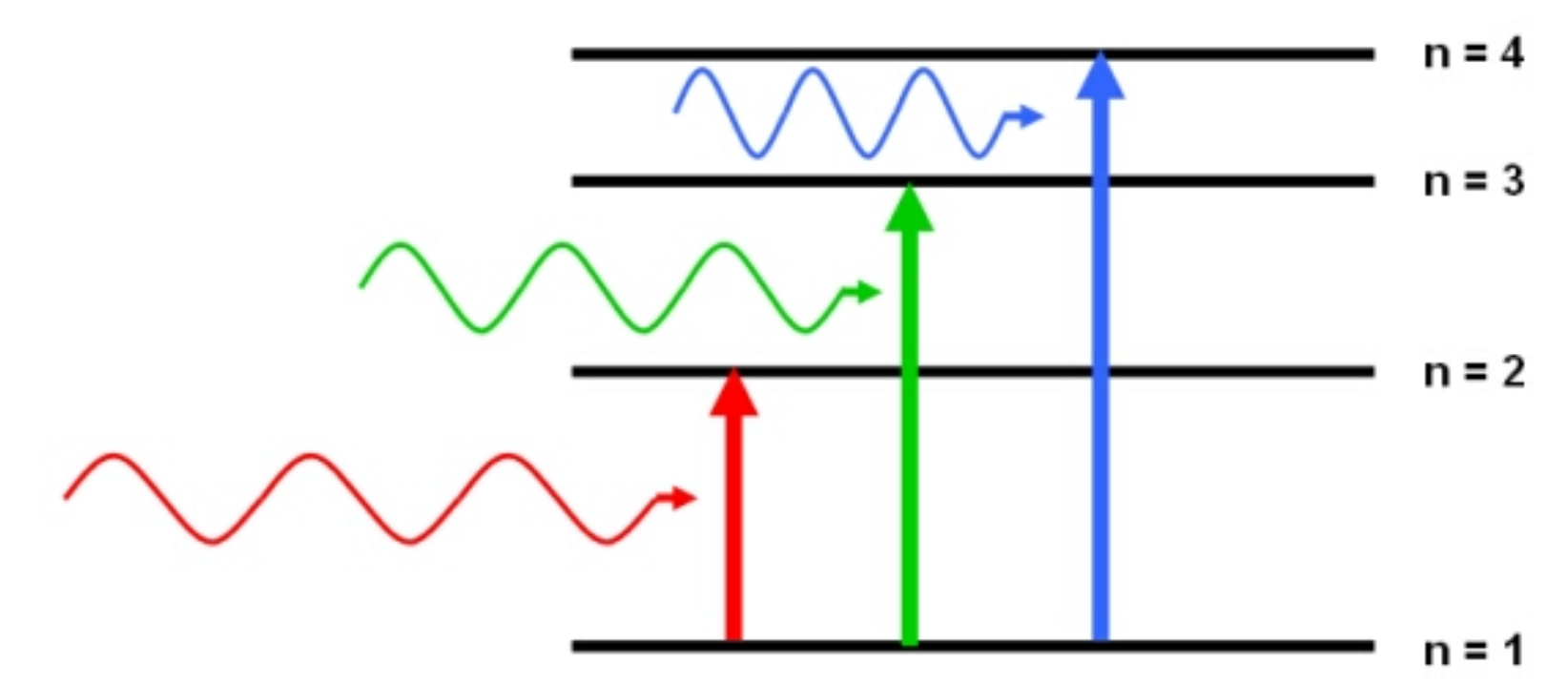
ionization

- The highest energy level (n=infinity) of a bound electron for a Hydrogen atom is 13.6eV
- If an incoming photon has an energy somewhat greater than this (but not MUCH greater) the photon will be absorbed, and the atom will be ionized
- i.e., the electron will be freed and the atom will lose an electron and become an ion, with positive charge

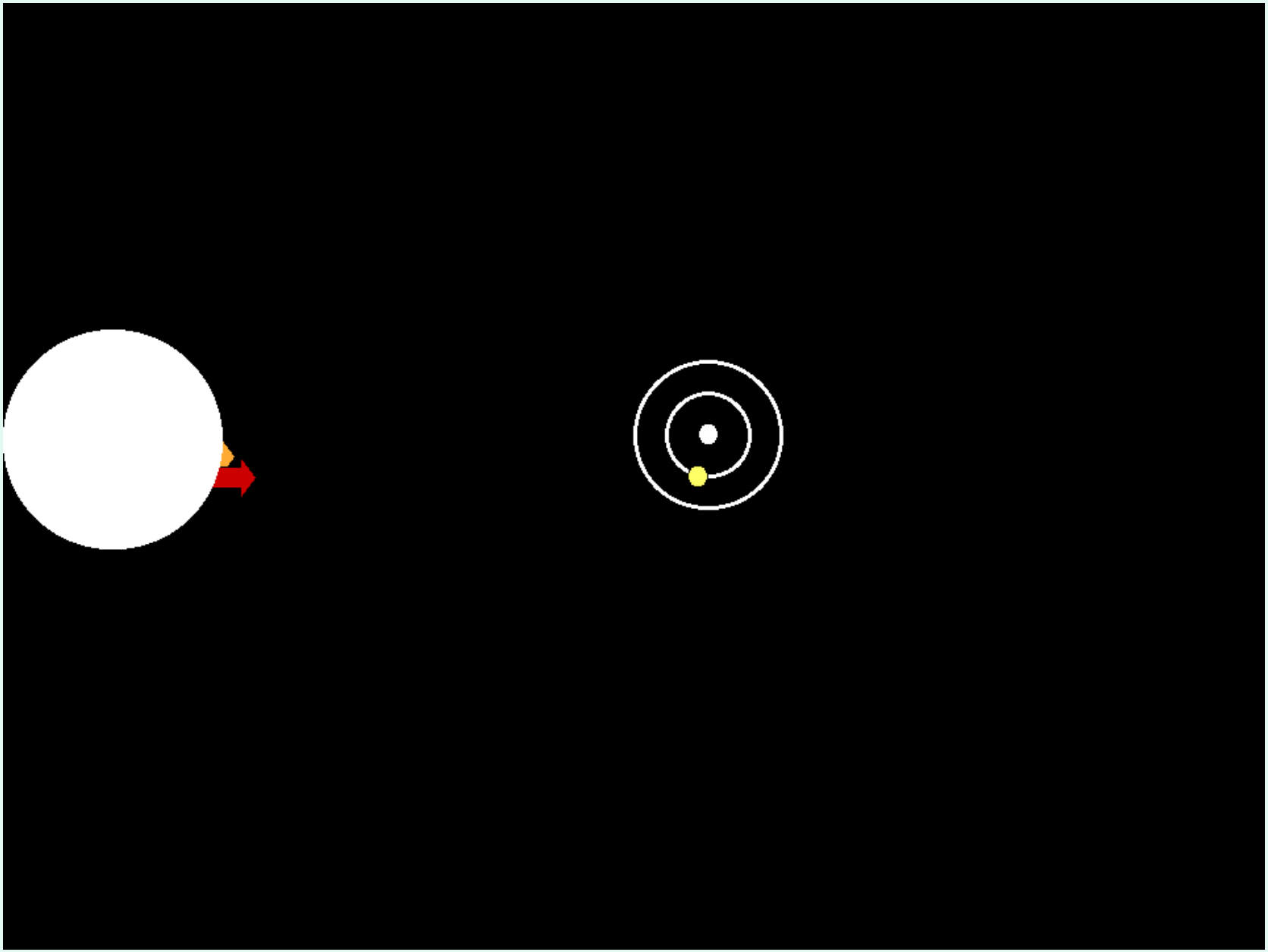
Electronic energy levels of Hydrogen, showing emission, absorption, ionization & recombination



hydrogen energy level diagram: absorption of 3 different photons



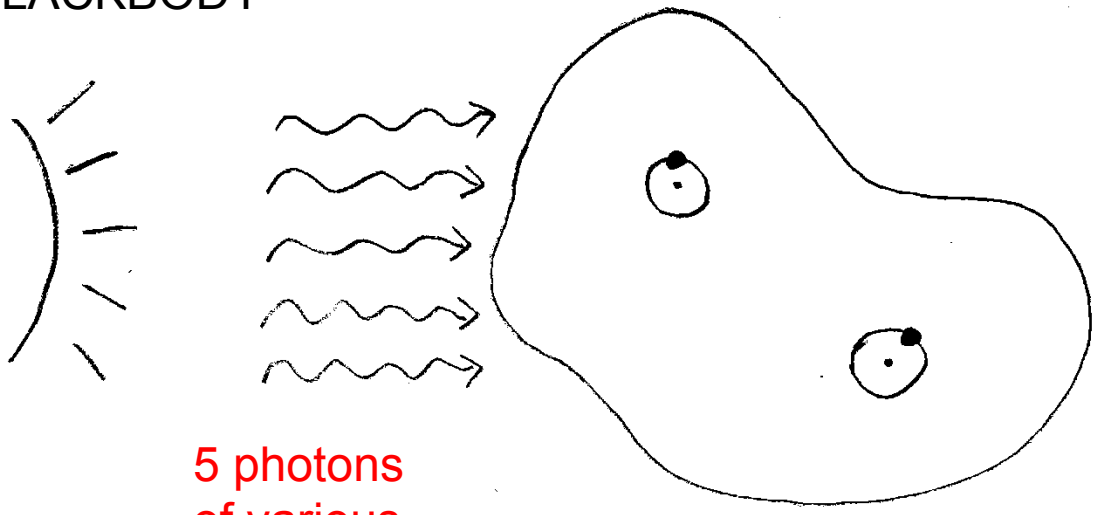
how do you know the wavelength of a photon that is created when the electron jumps from one energy level to the next?



Absorption & emission of photons by atoms in cloud: STEP 1

HOT
BLACKBODY

CLOUD WITH ATOMS



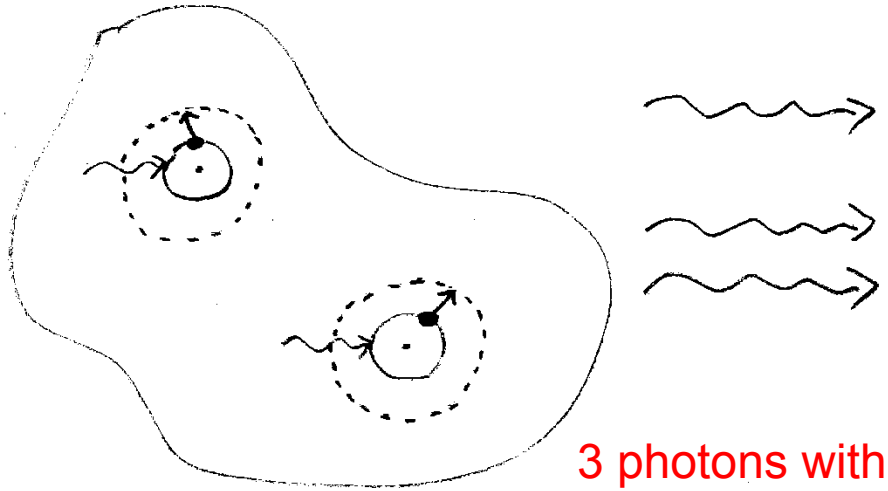
5 photons
of various
energies
about to
enter cloud

2 atoms with orbiting electrons
in the ground state

Absorption & emission of photons by atoms in cloud: STEP 2

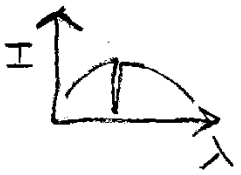
HOT
BLACKBODY

CLOUD WITH ATOMS



2 photons with the "right" energy are absorbed by atoms in cloud, putting atoms in excited state

3 photons with "wrong" energy are transmitted by cloud

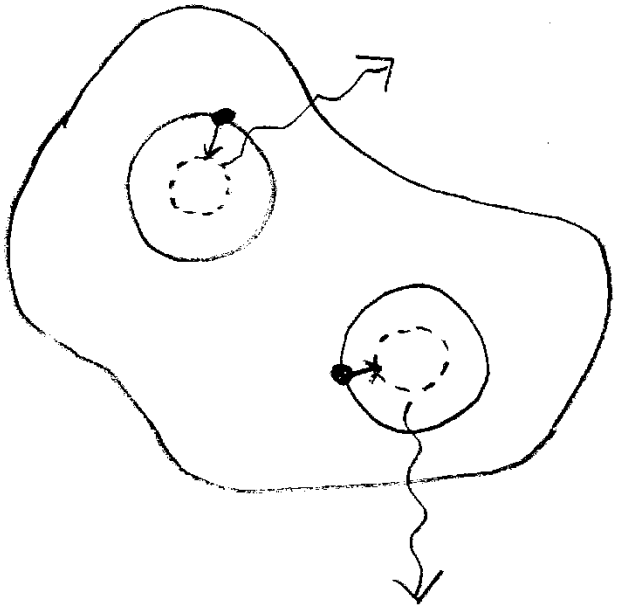


Observer in this direction sees absorption line spectrum

Absorption & emission of photons by atoms in cloud: STEP 3

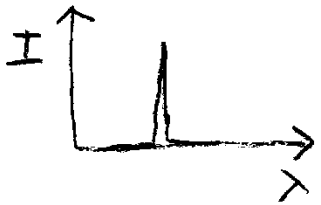
HOT
BLACKBODY

CLOUD WITH ATOMS
(a bit later…)



Very few of re-emitted photons go in original direction, so observer looking toward hot background still sees absorption line spectrum

Electrons spontaneously jump to lower energy levels, emitting photons in random directions. Atoms return to ground state.



Observer in this direction (who sees no hot background) sees emission line spectrum