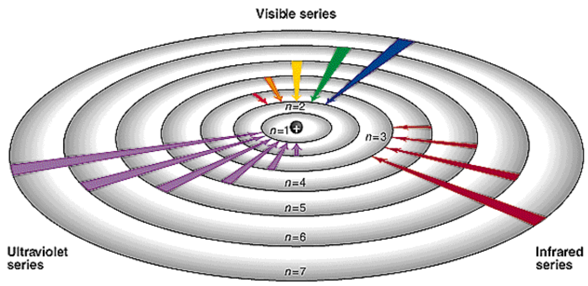
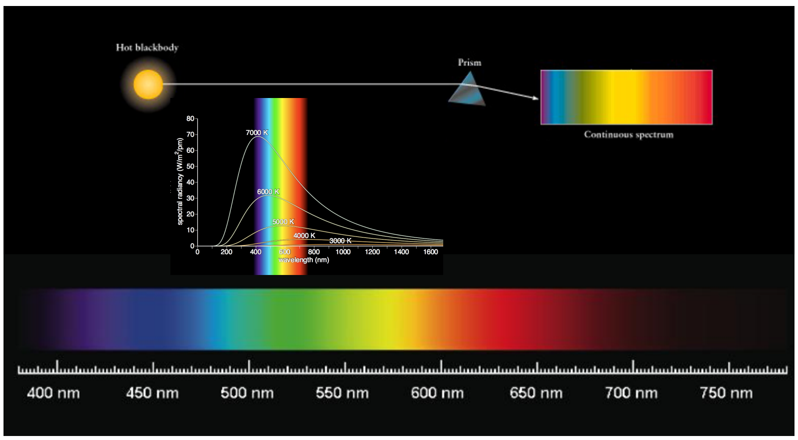
How Light and Matter Interact: 1



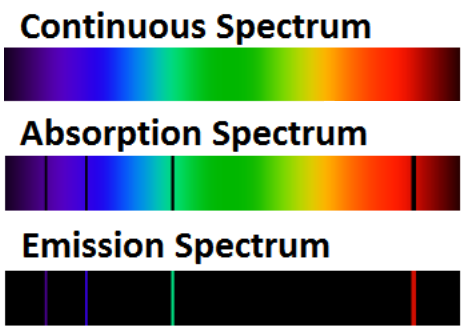
Blackbody Continuous Spectrum

Recall that a solid, or hot dense gaseous "perfect radiating" object emits a continuous spectrum with an intensity pattern known as a blackbody spectrum



Since a blackbody spectrum requires a perfect equilibrium in the object, don't expect to see them in nature! However, the universe itself is a perfect blackbody emitter (more on this when we talk about cosmology).

Three Main Types of Spectra



Continuous Spectrum
all wavelengths are present with no gaps

Absorption Spectrum
discrete gaps are present in an otherwise continuous spectrum (the "continuum")

Emission Spectrum
discrete emission is present with no underlying continuous spectrum (no continuum)

A continuous spectrum is <u>not</u> necessarily a blackbody spectrum.
Another common continuous spectrum is called the **"power-law" spectrum**.

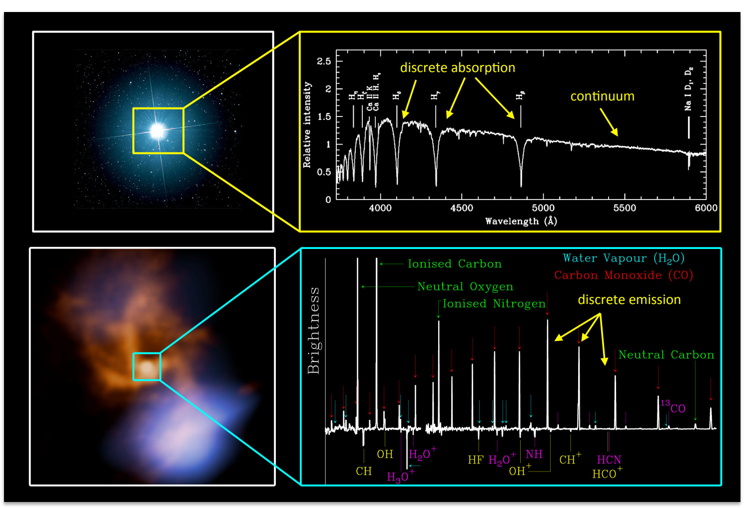
more on that later

Spectra of Stars and Hot Gas

What causes the discrete absorption or emission?
What can we learn from spectra?

The spectrum of a star is an absorption spectrum

The spectrum of a low density hot gas is an emission spectrum

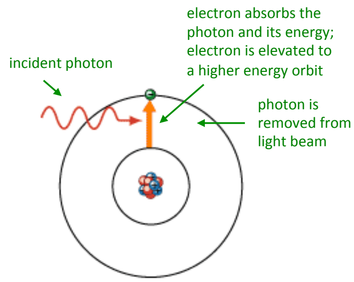


As suggested by the labels on the discrete absorption and emission lines; they originate from different elements, ions, and molecules → very powerful information for astronomers

Discrete Absorption and Emission

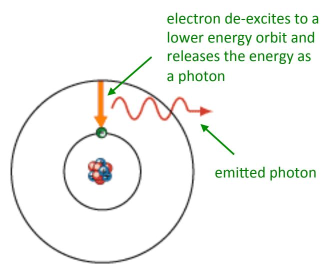
Discrete **absorption** occurs when a photon in a beam of light "excites" an electron in an atom from one *allowed orbit* to a higher energy *allowed orbit*

The energy of the absorbed photon equals the difference in the energies of the initial and final allowed electron orbits.



Discrete **emission** occurs when an already "excited" electron in an atom "de-excites" by dropping from a higher energy *allowed orbit* to a lower energy *allowed orbit*

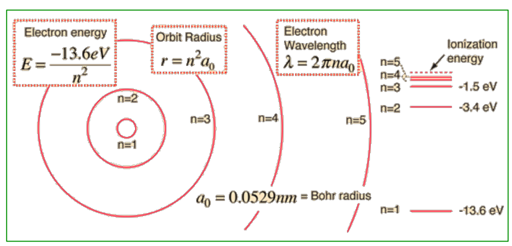
The energy of the emitted photon equals the difference in the energies of the initial and final allowed electron orbits.



Only Specific Photon Energies Interact with Atoms: Why?

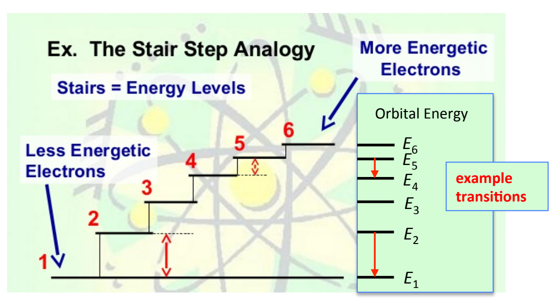
Recall that each element has its own set of unique allowed electron orbits; each orbit has a its corresponding energy.

(right) Example of hydrogen's set of allowed electron orbits and their energies



Stair Step Analogy: Like a ball must change positions from one stair to another, an electron must change positions from one orbit to another

The energy (wavelength) of the photon equals the energy difference between the energies of the electron orbits



example transition n=5 to n=4

$$E_5 - E_4 = hf = hc/\lambda$$

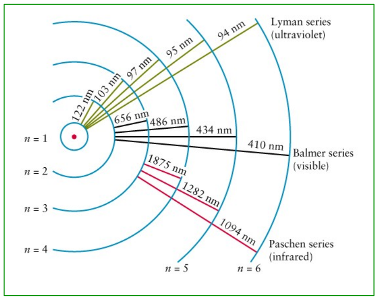
example transition n=2 to n=1

$$E_2 - E_1 = hf = hc/\lambda$$

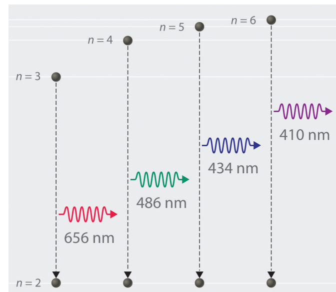
h = Planck's constant
f = frequency of photon
λ = wavelength of photon
c = speed lof light

All Combinations are Permitted – so, many possibilities

Many different photons can interact with an atom, but only those which have energies equal the difference between any two of the many allowed electron orbits.



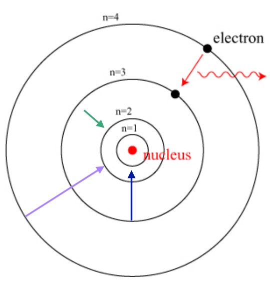
These are all the possible electron transitions for the first six orbits in a hydrogen atom. For each transition, the wavelengths of the emitted or absorbed photons are given; the wavelength corresponds to the energy difference of the orbits.



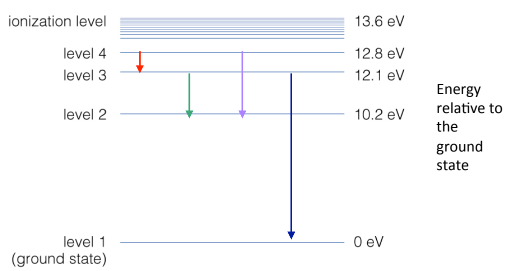
The energy diagram for downward transitions for which the lower orbit is n=2. The wavelength of the emitted photons are shown. This set of transitions is called the Balmer series, since it yields a spectrum of several emission features in the visible spectrum.

The hydrogen Balmer series emission "lines" corresponding to the electron transitions:
n=3→2 (656.3 nm), **n=4→2 (486.1 nm)**, **n=5→2 (434.0 nm)**, and **n=6→2 (410.1 nm)**.

Examples: The hydrogen atom spectrum



Three example transitions correspond to n=4→3, n=3→2, and n=4 →2.



Energy diagram of the electron orbits. The energies are measured in electron-Volts (eV). Downward arrows give the three example transitions n=4→3, n=3→2, and n=4→3. Each transition will result in the emission of a photon.

n=4→3 E(photon) = 12.8 – 12.1 = 0.70 eV : λ = 1875 nm infrared

n=3→2 E(photon) = 12.1 – 10.2 = 1.90 eV : λ = 656.3 nm visible (red)

n=4→2 E(photon) = 12.8 – 10.2 = 2.60 eV : λ = 486.1 nm visible (blue/green)

n=3→1 E(photon) = 12.1 – 0.0 = 12.1 eV : λ = 97.3 nm ultraviolet

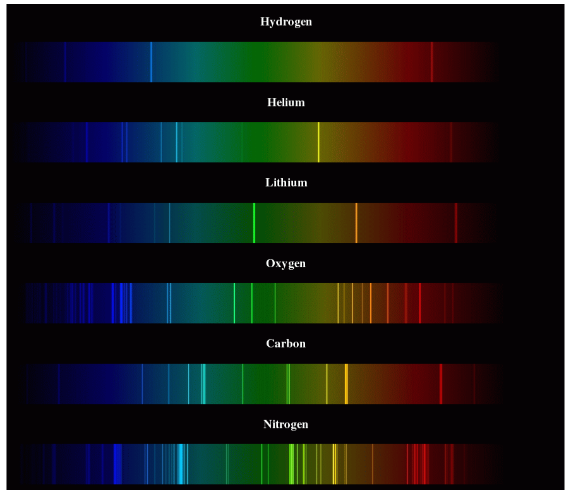
$E = hc/\lambda$ thus $\lambda = hc/E$

Examples of the Emissions Spectra for Common Elements

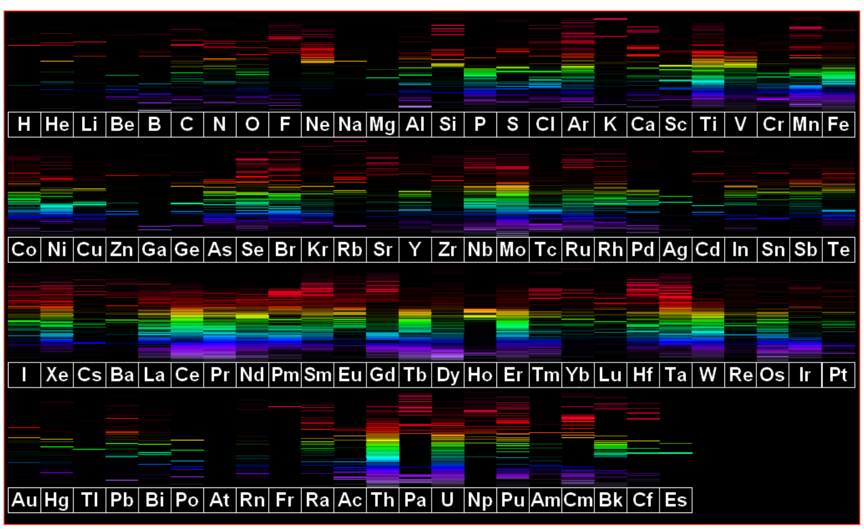
Since each element has its own unique set of allowed orbits…

- each elements interacts with a unique set of photons
- **each element has its own unique spectrum**

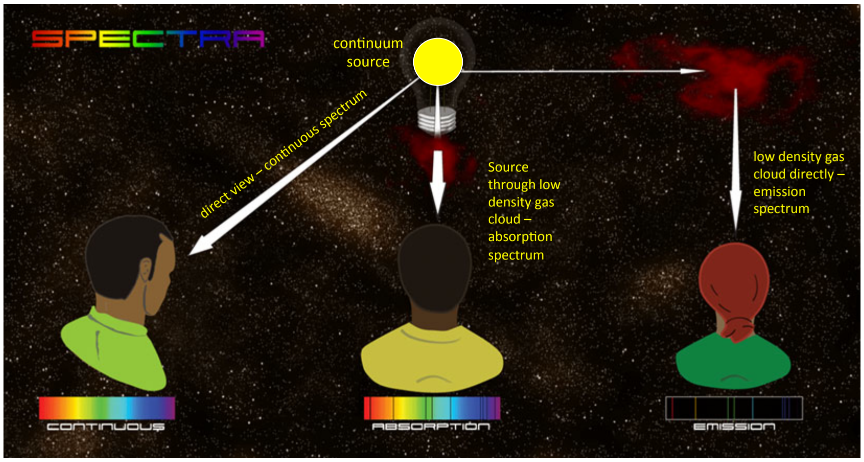
This means that we can measure the presence and relative abundances of the elements in astronomical objects by analyzing their spectra.



The library of visible-band emission spectra for the periodic table



Type of Spectrum Depends Upon How You View Objects

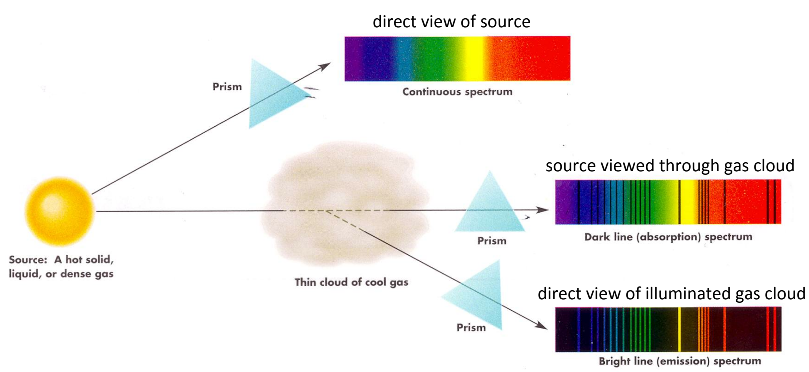


All photons from the source make it to the observer

Photons that excite electrons in the atoms in the gas cloud are absorbed; all other photons from the source make it to the observer

Photons that excite electrons in the atoms in the gas cloud are re-emitted in random directions when the electrons de-excite. Some of these photons are emitted in the direction to the observer

Type of Spectrum Depends Upon How You View Objects

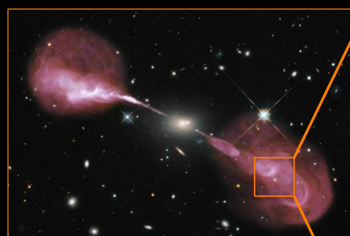


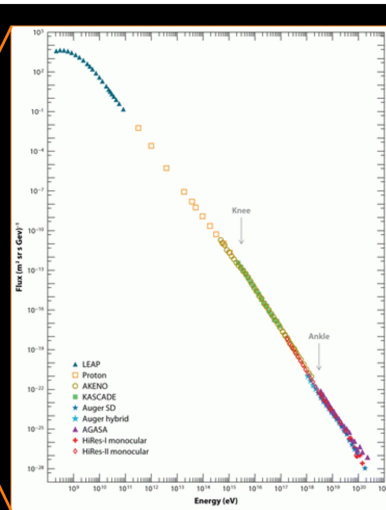
These three types of spectra tells us a great deal: including the illumination relative to observer, and the temperature, density, chemical composition of objects!

The Power-Law Spectrum

This is a non-thermal continuous spectrum

Visual + radio (false color pink) image of a galaxy.

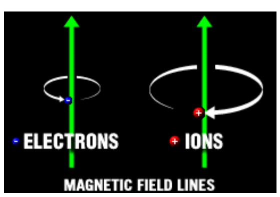




Free fast moving electrons and ions in the region of strong magnetic fields will emit low energy photons in the radio part of the electromagnetic spectrum.

The stronger the magnetic field and the faster the electrons/ions move, the higher the energy of the emitted photons.

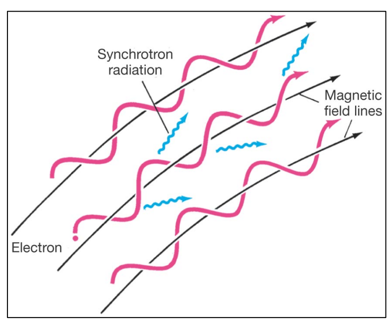
Power law spectra are generated by freely moving charged particles that are confined in magnetic fields.



Electrons and ions spiral around the magnetic field lines.

Electrons spiral in the opposite direction that the ions spiral.

Spiral motion means that the electron is accelerating, and accelerating charged particles emit light.



The emitted photons from charged particles accelerating in magnetic fields are called **synchrotron radiation**.

The power law spectrum tells us the strength of the magnetic field and the energy budget of the source of electrons.