An introduction to

Spectra

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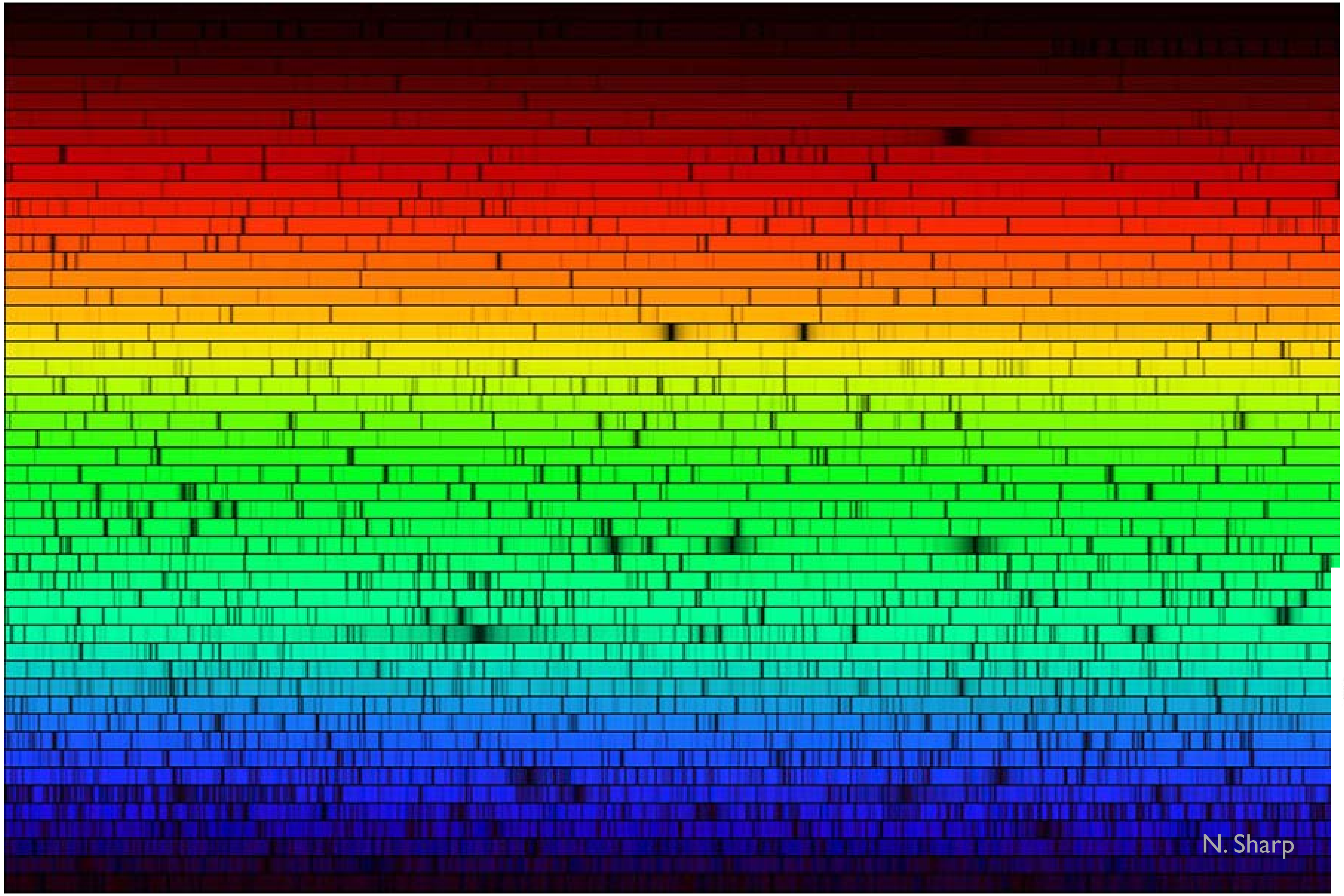
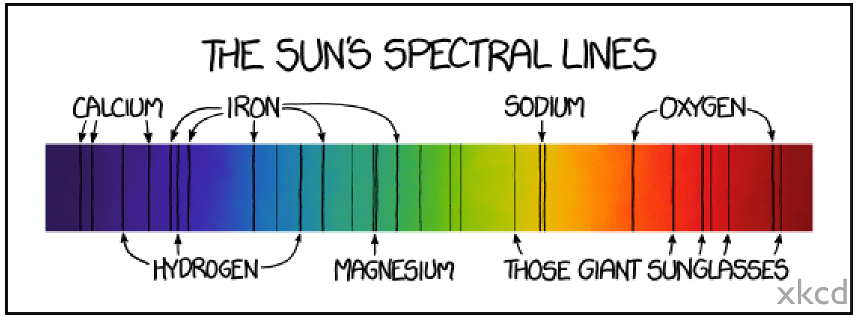
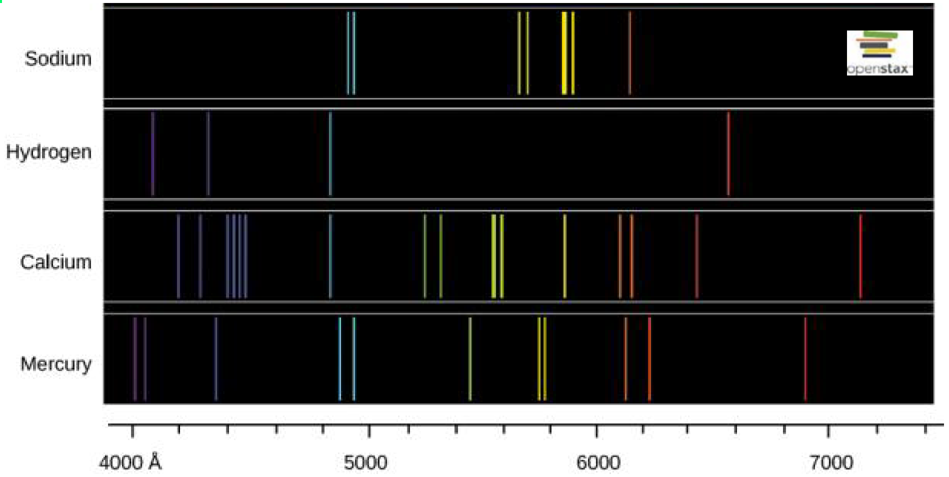
Visible spectrum from the Sun

"Spectrum" (plural = spectra): intensity of light over a range of wavelengths



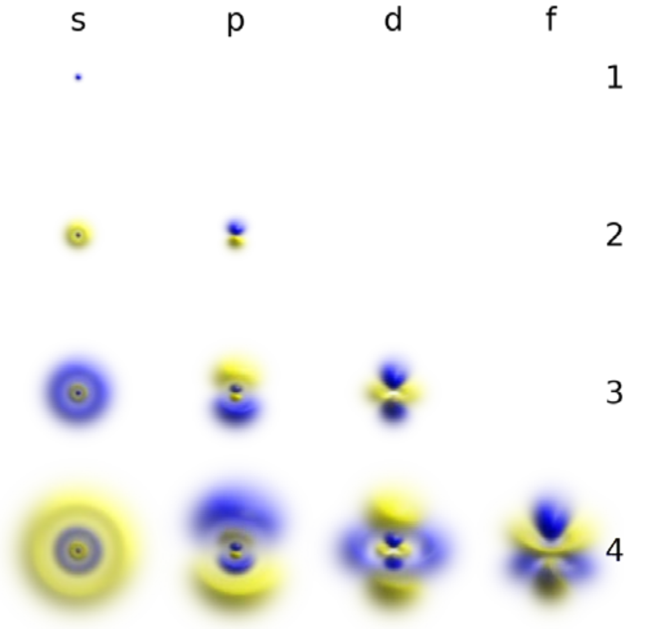
- Gaps in a nearly continuous spectrum are "absorption lines"
- Spectra with light only present at a handful of wavelengths show "emission lines"
- The presence of lines has to do with atoms and molecules in an object





Detour inside the atom

- Atoms consist of a tiny positively charged nucleus at the core, surrounded by electron(s) whose position are described by a probability distribution
- For our purposes, we can instead use the Bohr model of the atom, where the electrons orbit the nucleus in neat circles
- Regardless of your picture, the atom is mostly empty space
  - Electron clouds extend out to ~10^{-10} m = 0.1 nm = 1 Å
  - Nuclei only span ~10^{-15} m = 1 fm
    - The atomic nucleus consists of protons and neutrons whose positions themselves are described by probability distributions
      … but we don't need to worry about that here!
    - Protons provide the positive charge, neutrons are neutral
- The number of protons in the atom defines the element, the number of neutrons defines the isotope of that element



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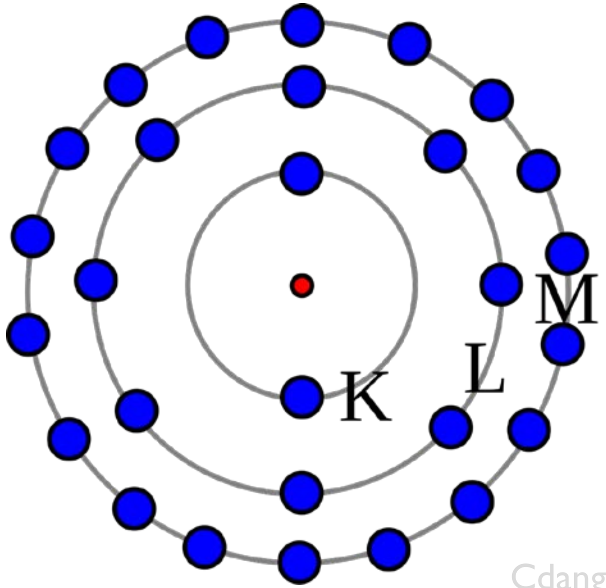

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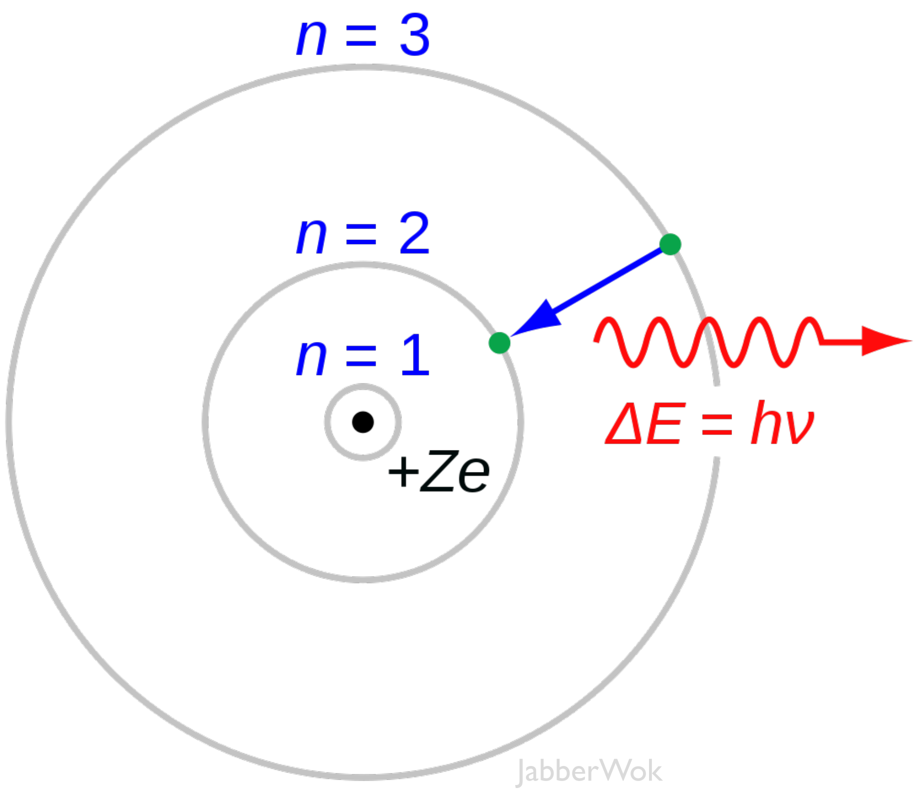
Quantization of energy

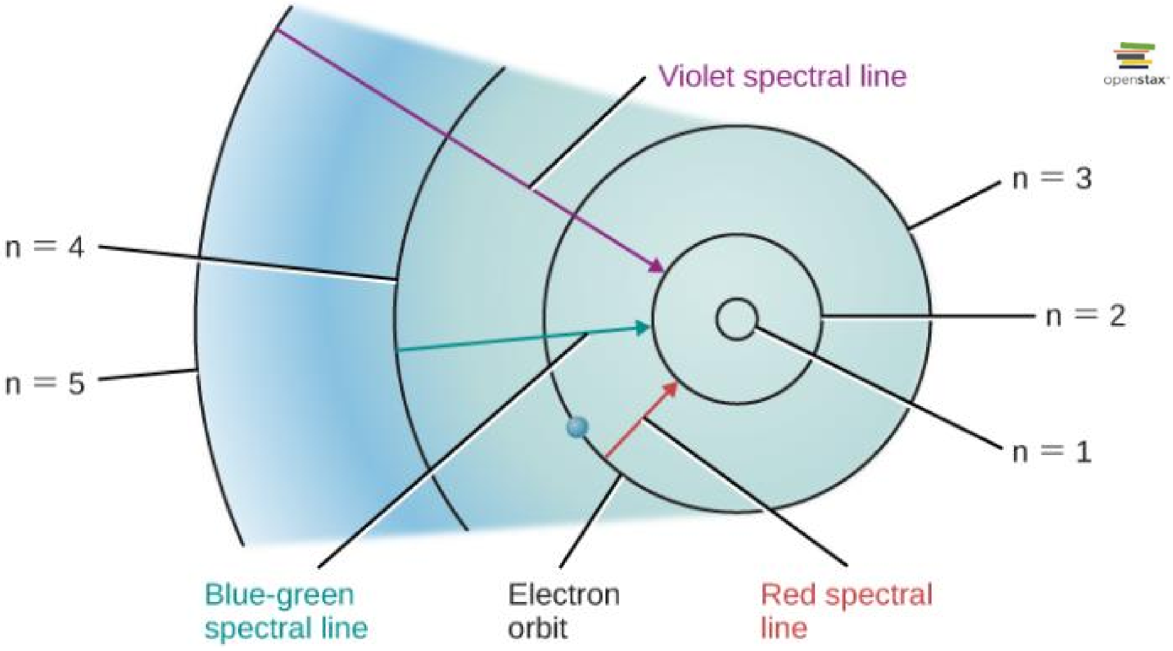
- The "quantum" in quantum mechanics indicates that, at the smallest scales, nature only allows discrete configurations of matter
- The energy bond of an electron to a nucleus can have many different values ("atomic excited states"), but only certain discrete values are allowed.
  These are known as "energy levels".
- An electron can move from one energy level to another by the atom absorbing or emitting a photon.
  - absorbing leads to "excitation"
  - emitting leads to "deexcitation"
- The frequency of the photon connecting two energy levels is defined by the energy difference:
  $E \quad = hff$, where h is Planck's constant = 6.626×10^{-34} Js
  - high frequency = short wavelength = more energy
  - low frequency = long wavelength = less energy

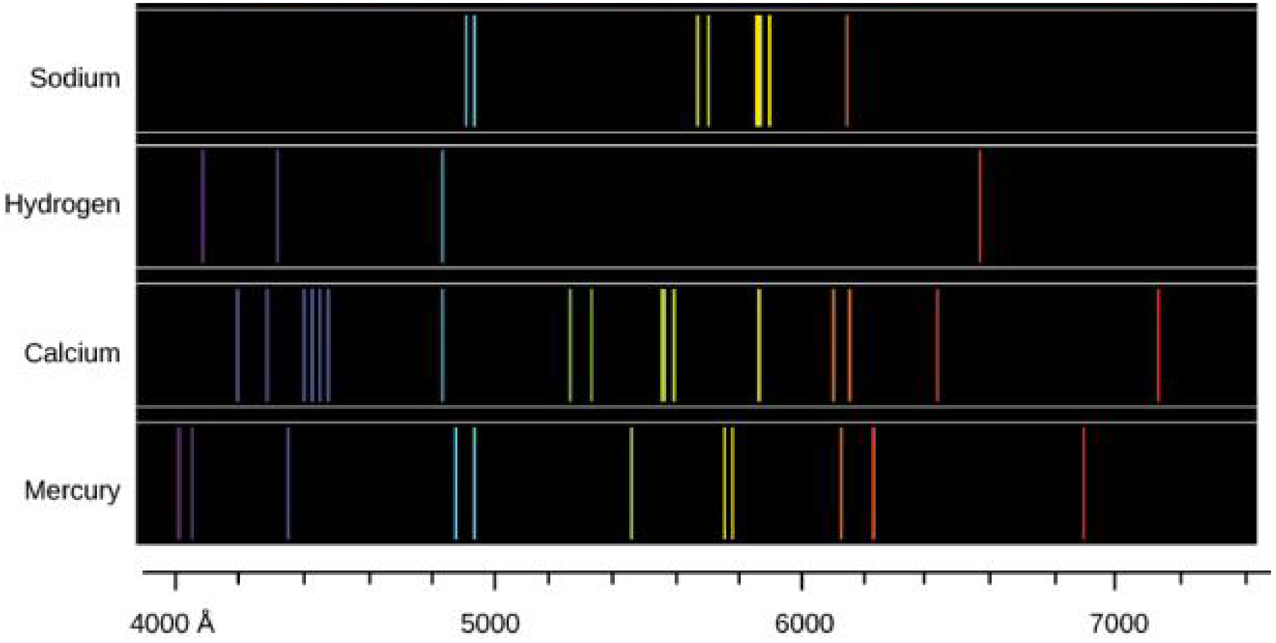


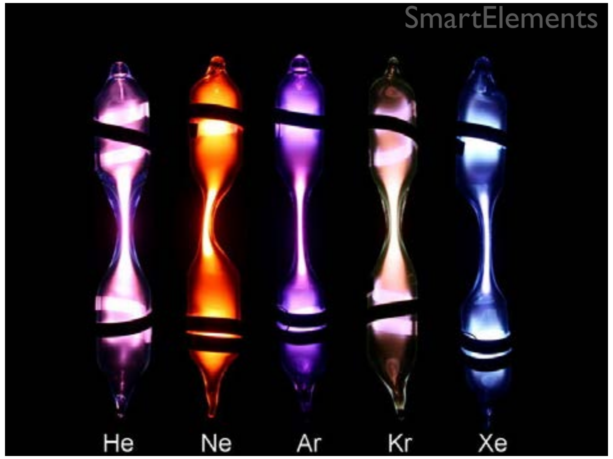
1 X-ray carries ~1 billion times less energy than 1 radio wave

Atomic Spectra

- Now we have a picture to explain absorption and emission lines



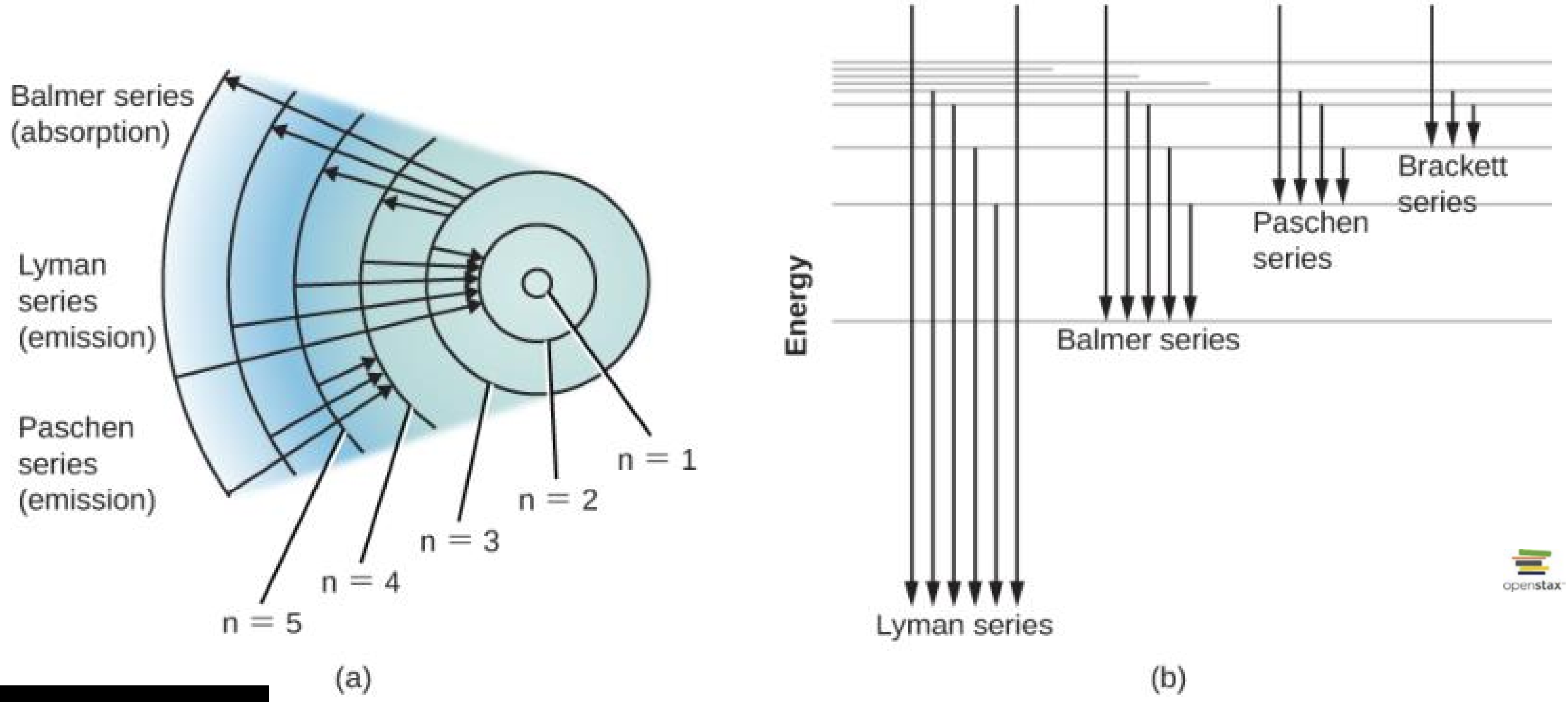


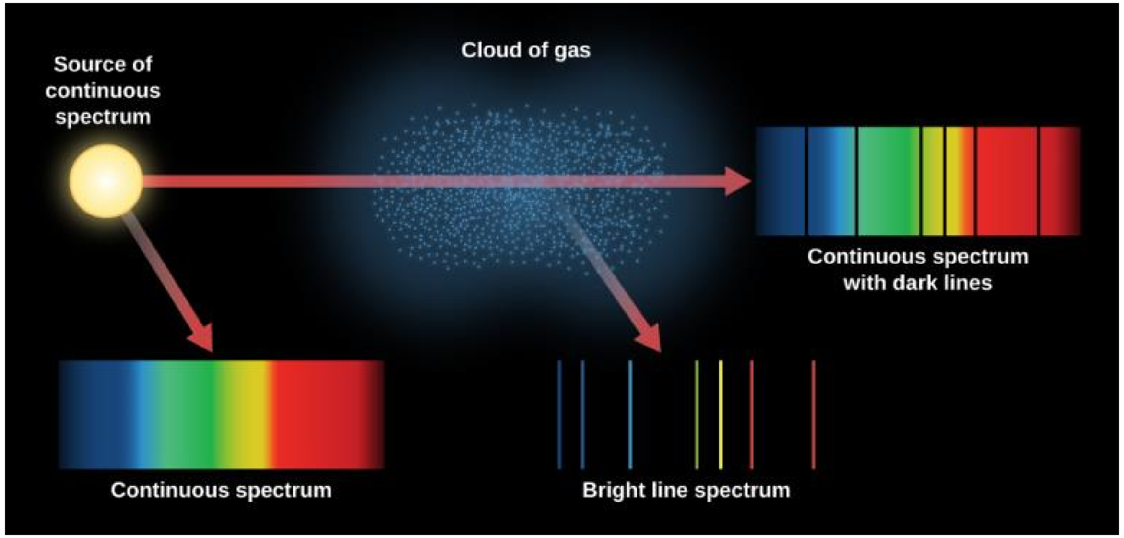


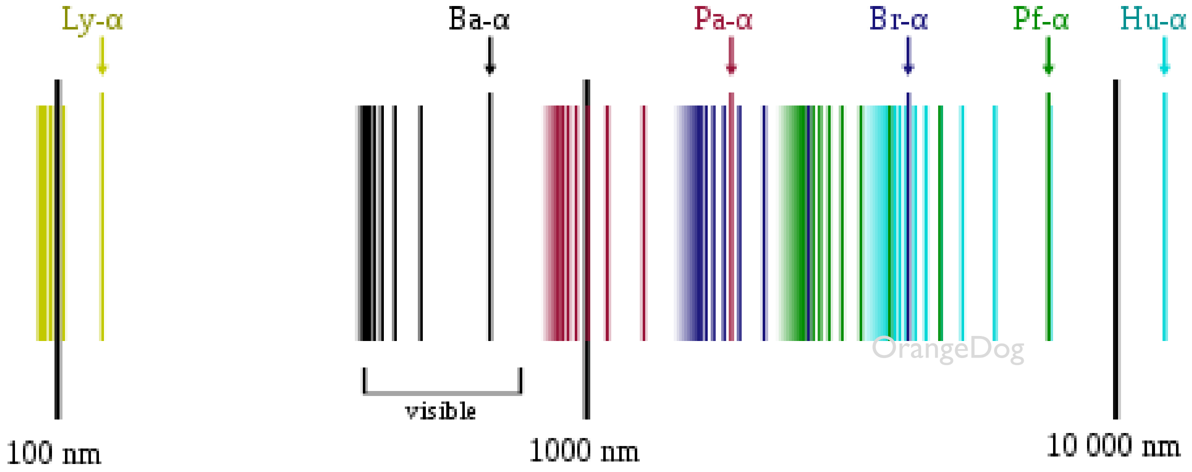
- The energy levels are located at different energies for different atoms and atoms with more electrons have more transition probabilities, hence the different absorption/emission spectra for different atoms

The hydrogen atom

"Series" group together
excitations from
or
de-excitations to
a particular energy level







Atomic ionization

- An "ion" is a charged atom
- Ionization is the process of removing one or more electrons from an atom, changing the atomic charge
- The amount of energy to remove an electron depends on the atom,
  as well as the energy level that the electron is in
- The fraction of a given atom in a given ionization (or excitation) state is a direct indicator of the environmental conditions for that atom