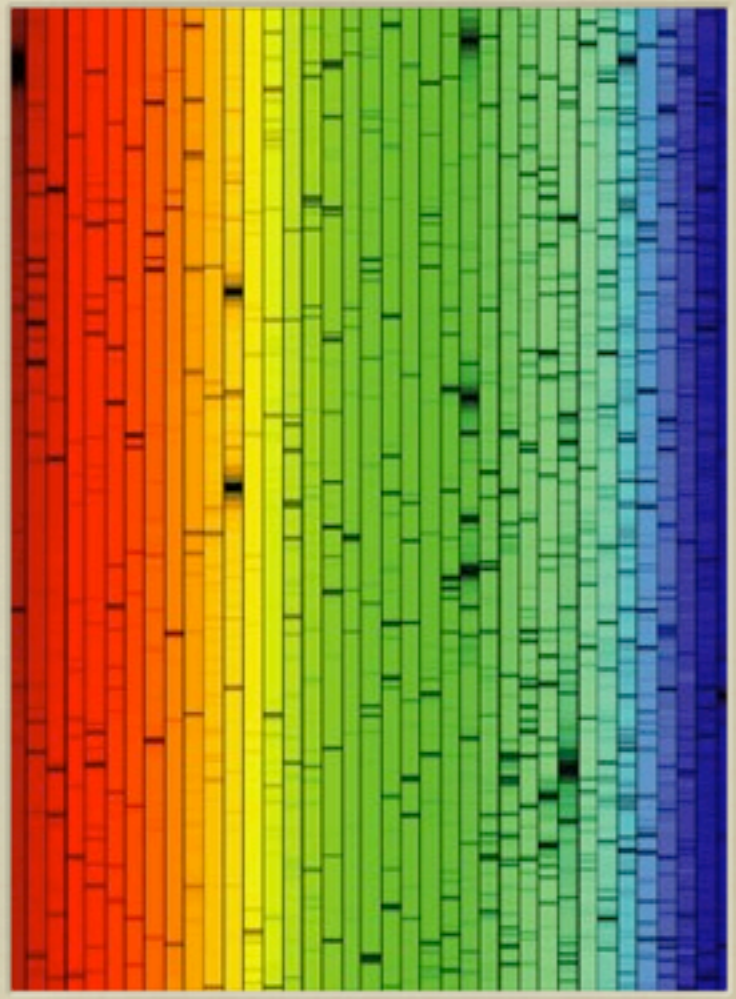
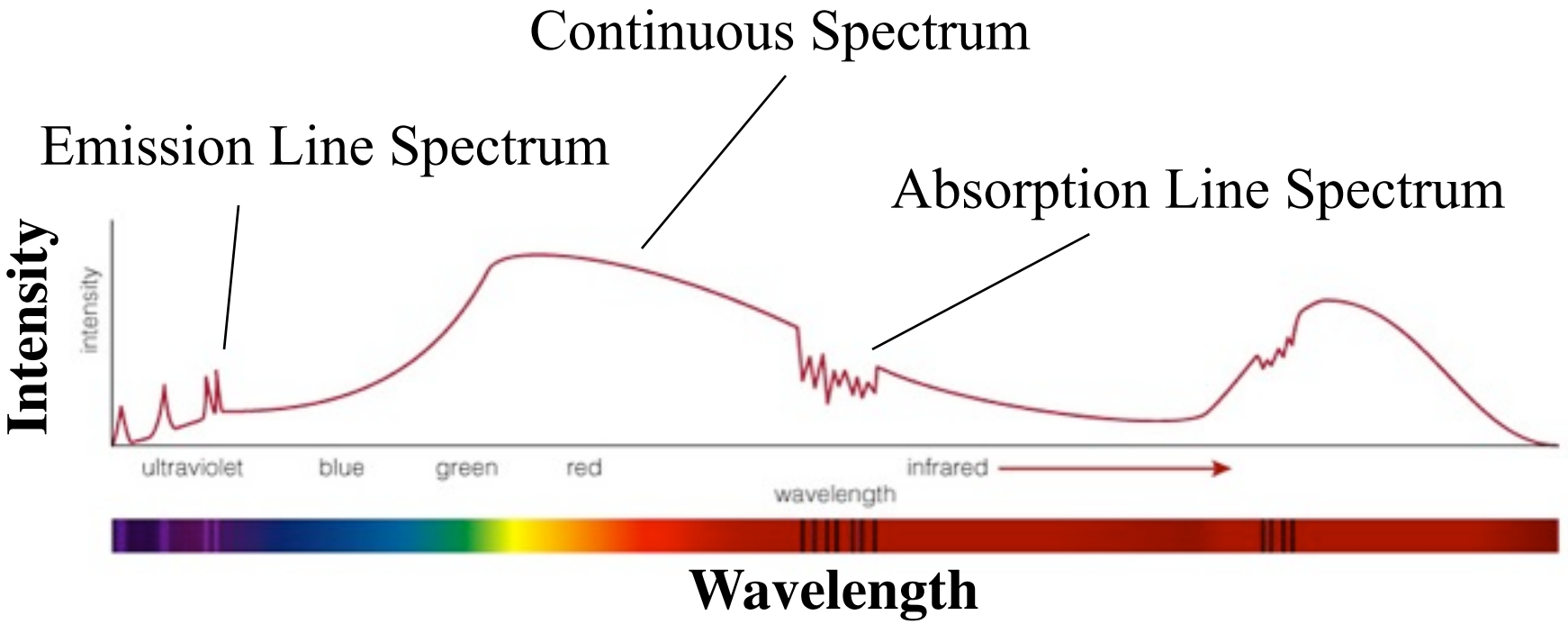
Today

- Kirchoff's Laws
  - Emission and Absorption
  - Stellar Spectra & Composition
- Doppler Effect & Motion
  - Extrasolar Planets



Three basic types of spectra

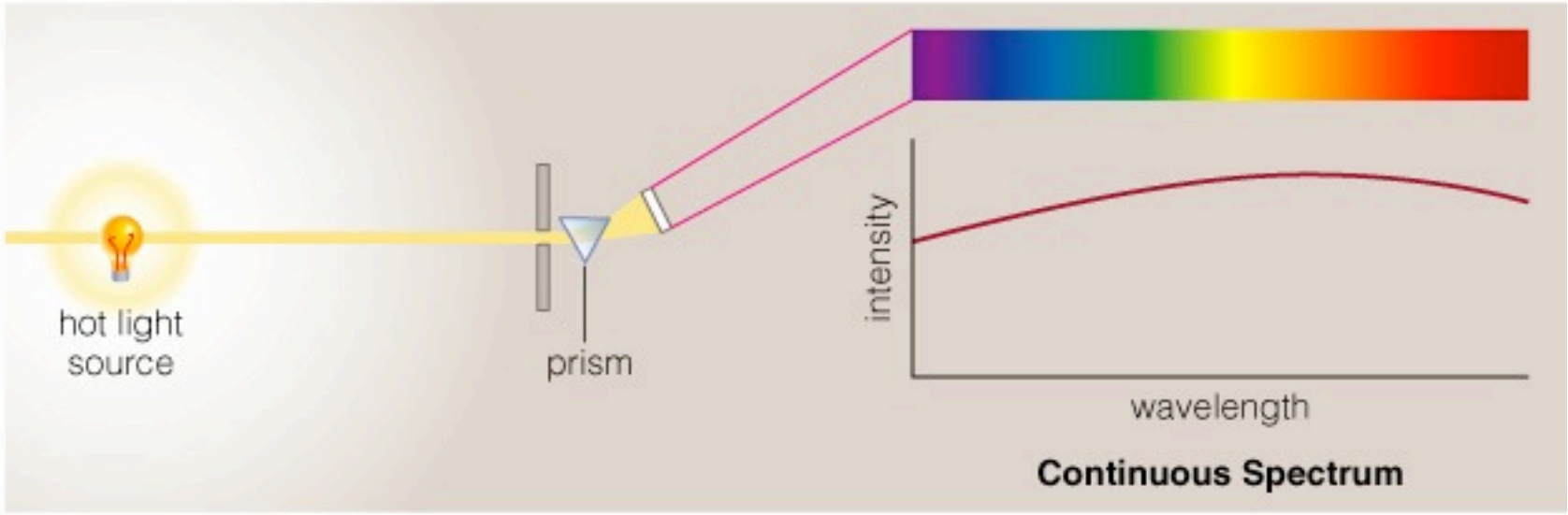


Spectra of astrophysical objects are usually combinations of these three basic types.

Kirchoff's Laws

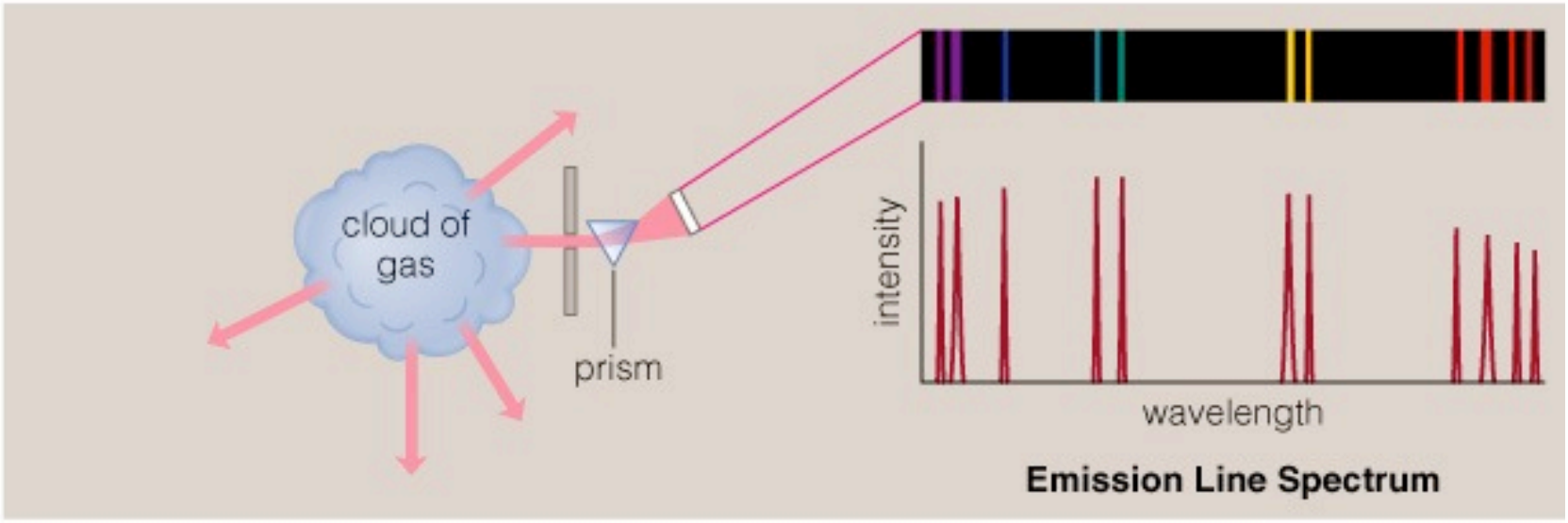
- Hot, dense objects emit a
  - **continuous spectrum** e.g., a light bulb
    - light of all colors & wavelengths
    - follows thermal distribution
    - obeys Wien's & Steffan-Boltzmann Laws.
- Hot, diffuse gas emits light only at specific wavelengths.
  - **emission line spectrum** e.g., a neon light
- A cool gas obscuring a continuum source will absorb specific wavelengths
  - **absorption line spectrum** e.g., a star

Continuous Spectrum



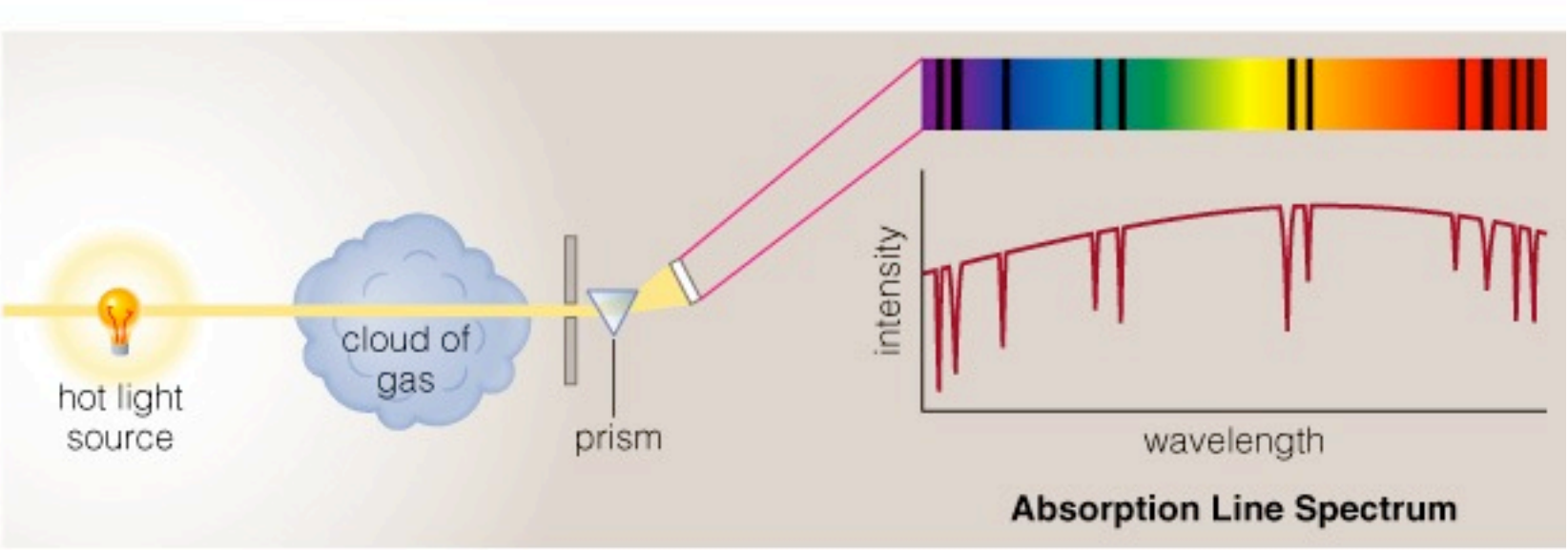
- The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.

Emission Line Spectrum



- A thin or low-density cloud of gas emits light only at specific wavelengths that depend on its composition and temperature, producing a spectrum with bright emission lines.

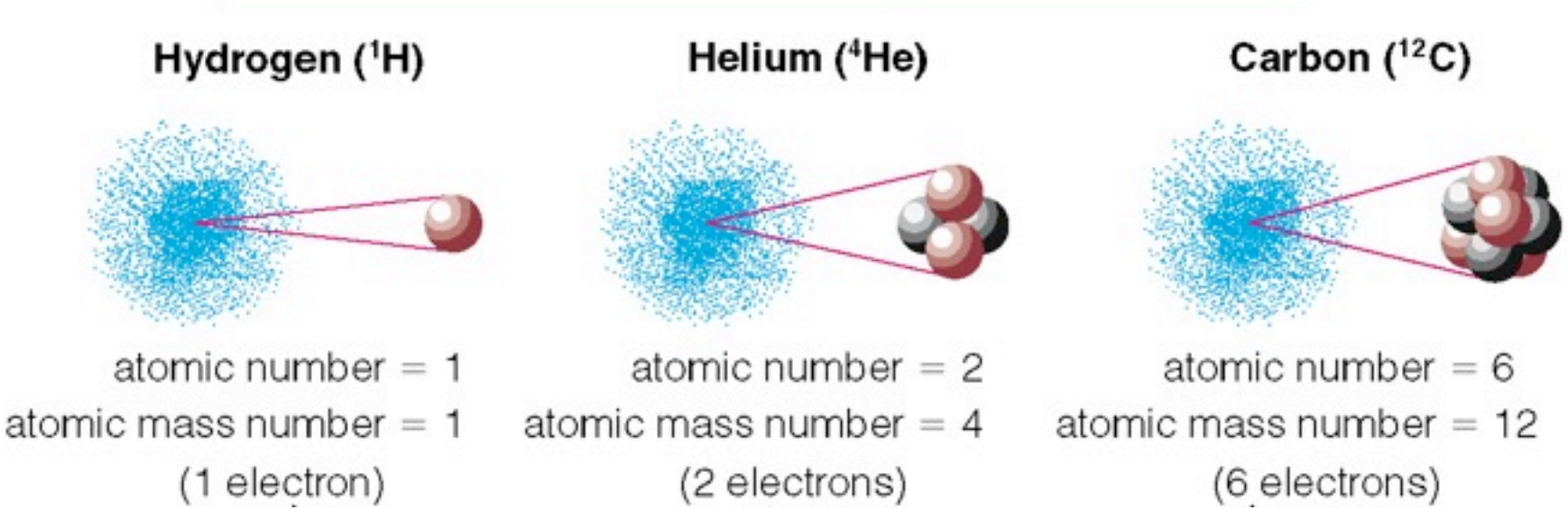
Absorption Line Spectrum



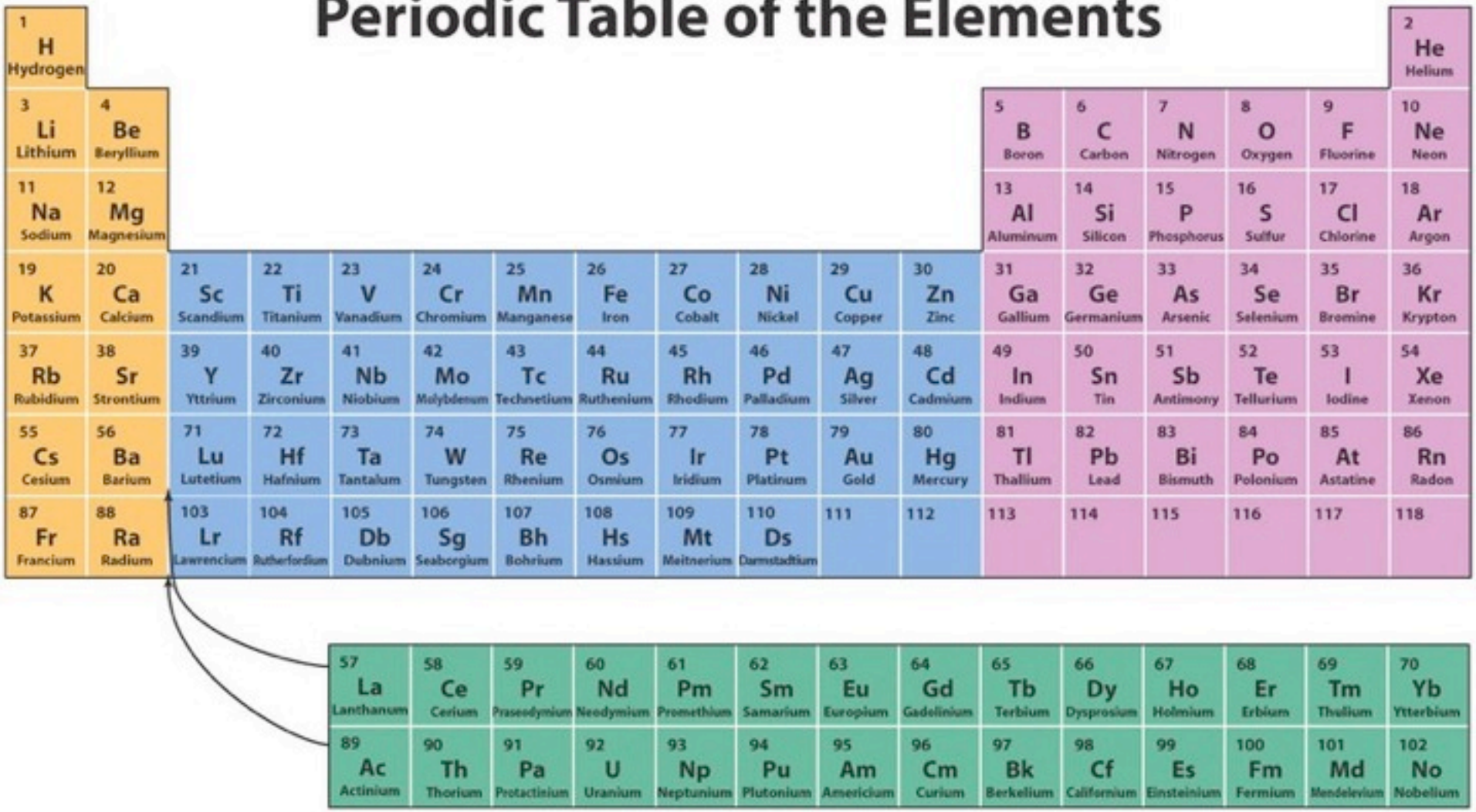
- A cloud of gas between us and a light bulb can absorb light of specific wavelengths, leaving dark absorption lines in the spectrum.

Atomic Terminology

- Atomic Number = # of protons in nucleus
- Atomic Mass Number = # of protons + neutrons

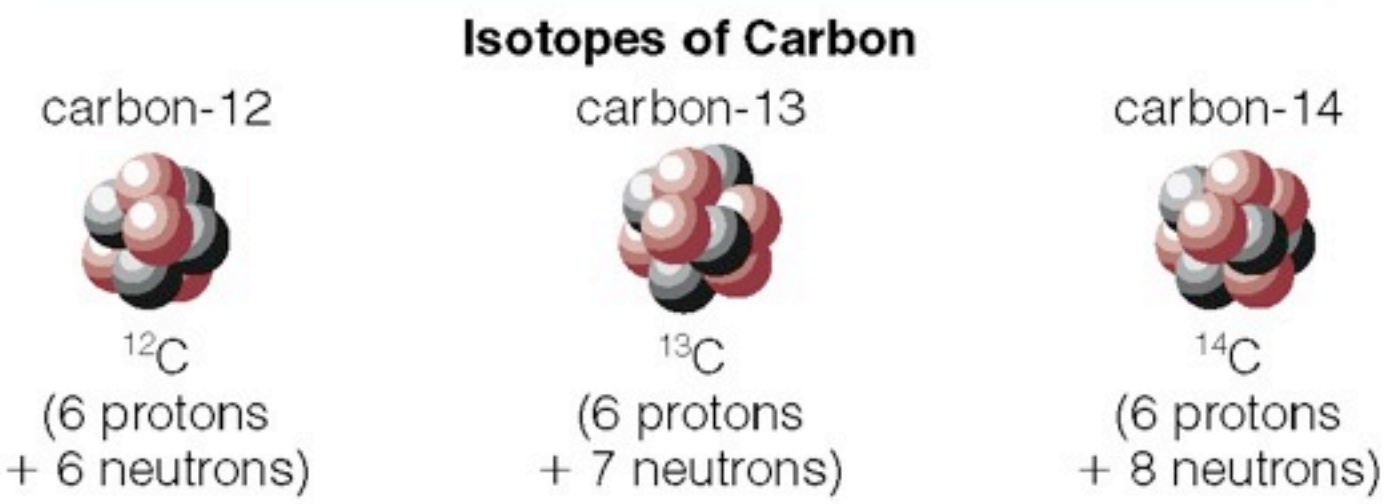


Periodic Table of the Elements



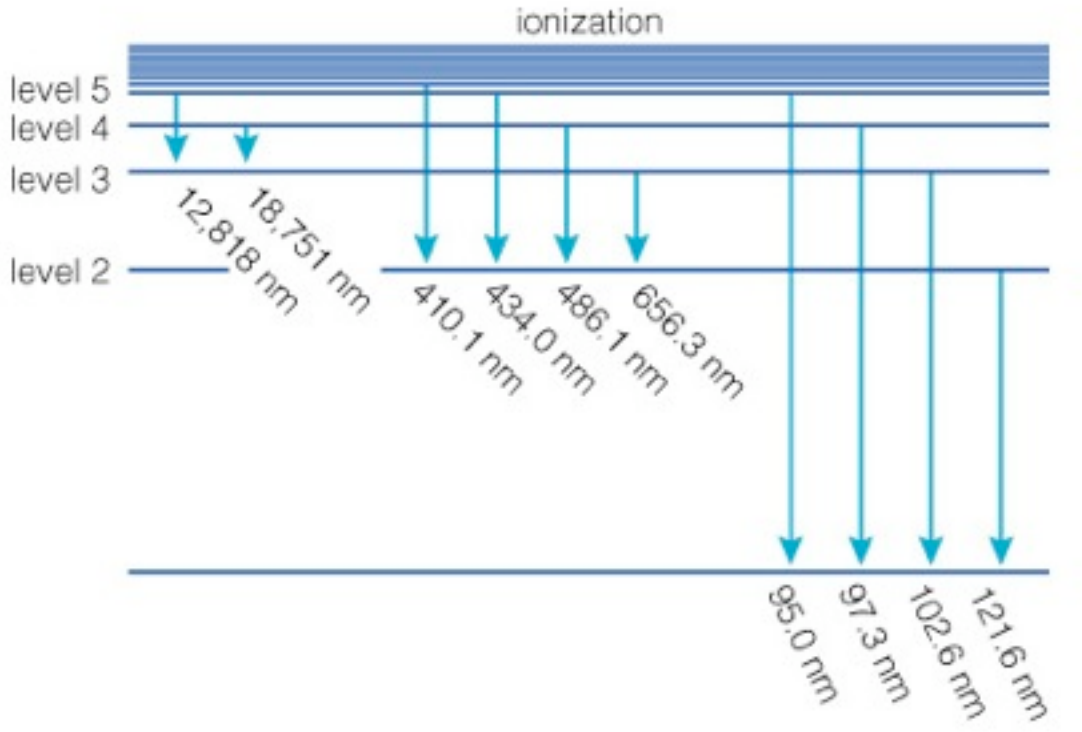
Atomic Terminology

- Isotope: same # of protons but different # of neutrons (^{4}He, ^{3}He)



- Molecules: consist of two or more atoms (H_2O, CO_2)

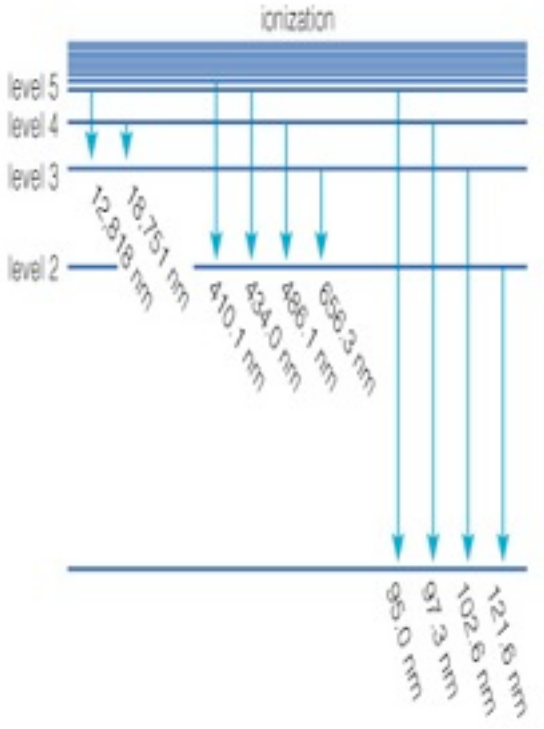
Chemical Fingerprints

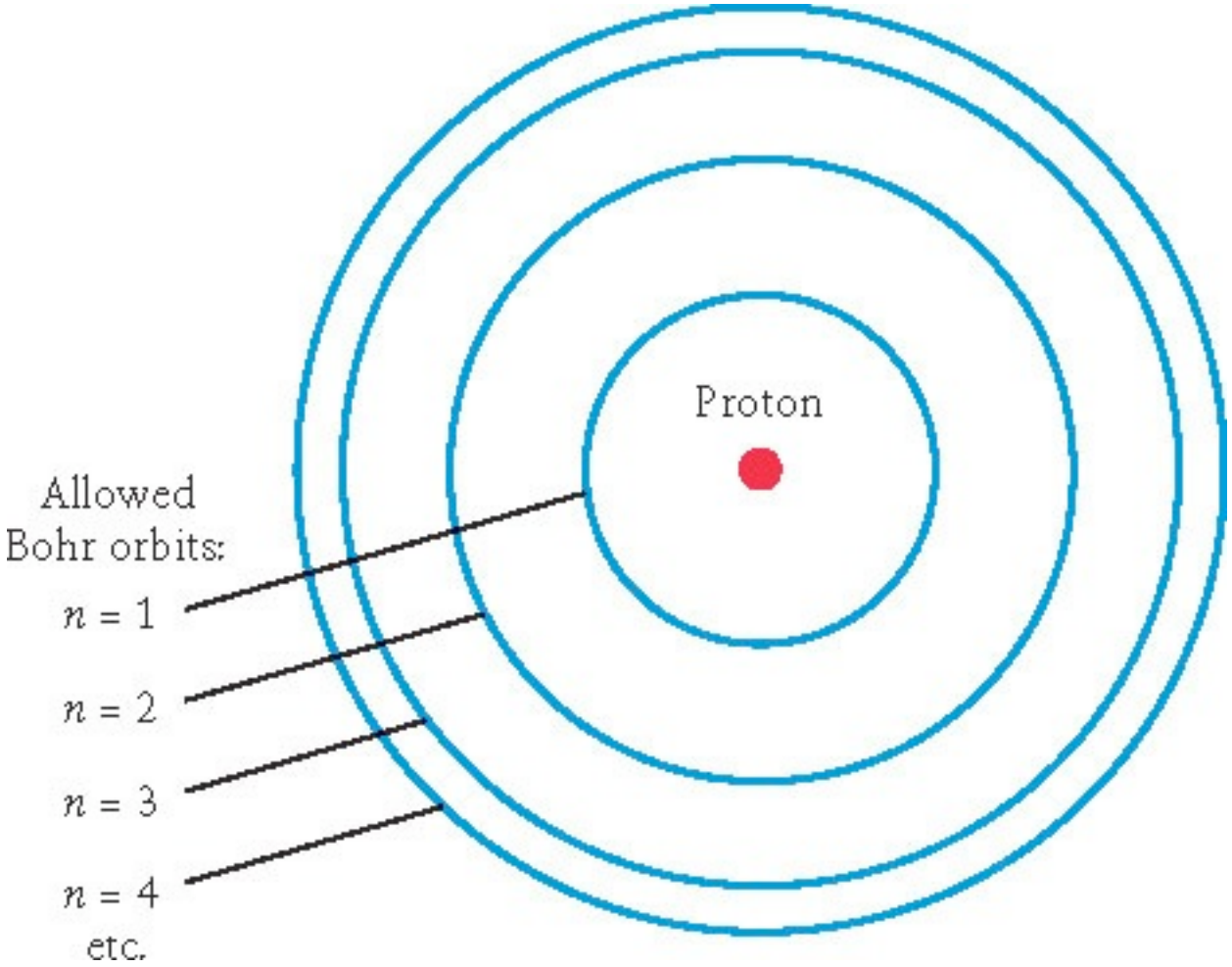


Energy levels of hydrogen

- Each type of atom has a unique set of energy levels.
- Each transition corresponds to a unique photon energy, frequency, and wavelength.

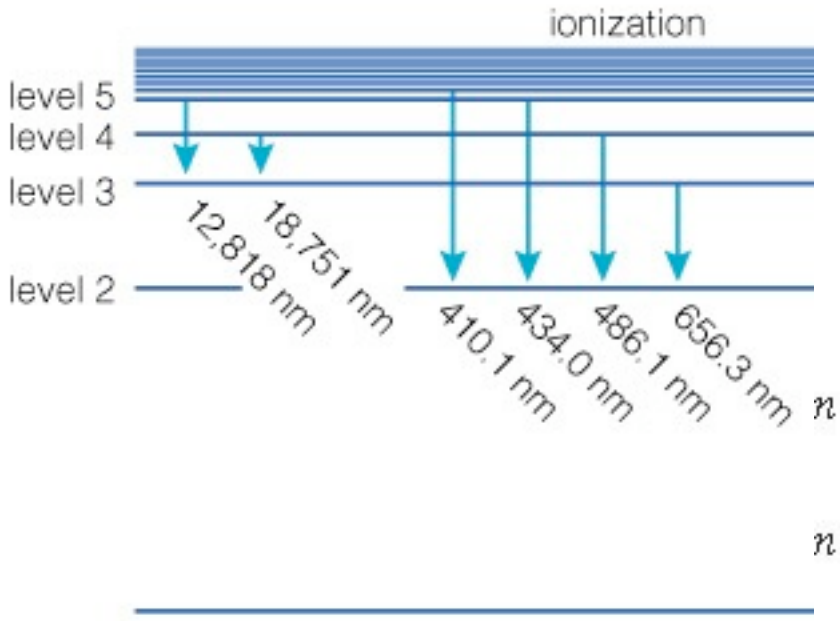
Possible Electron orbits

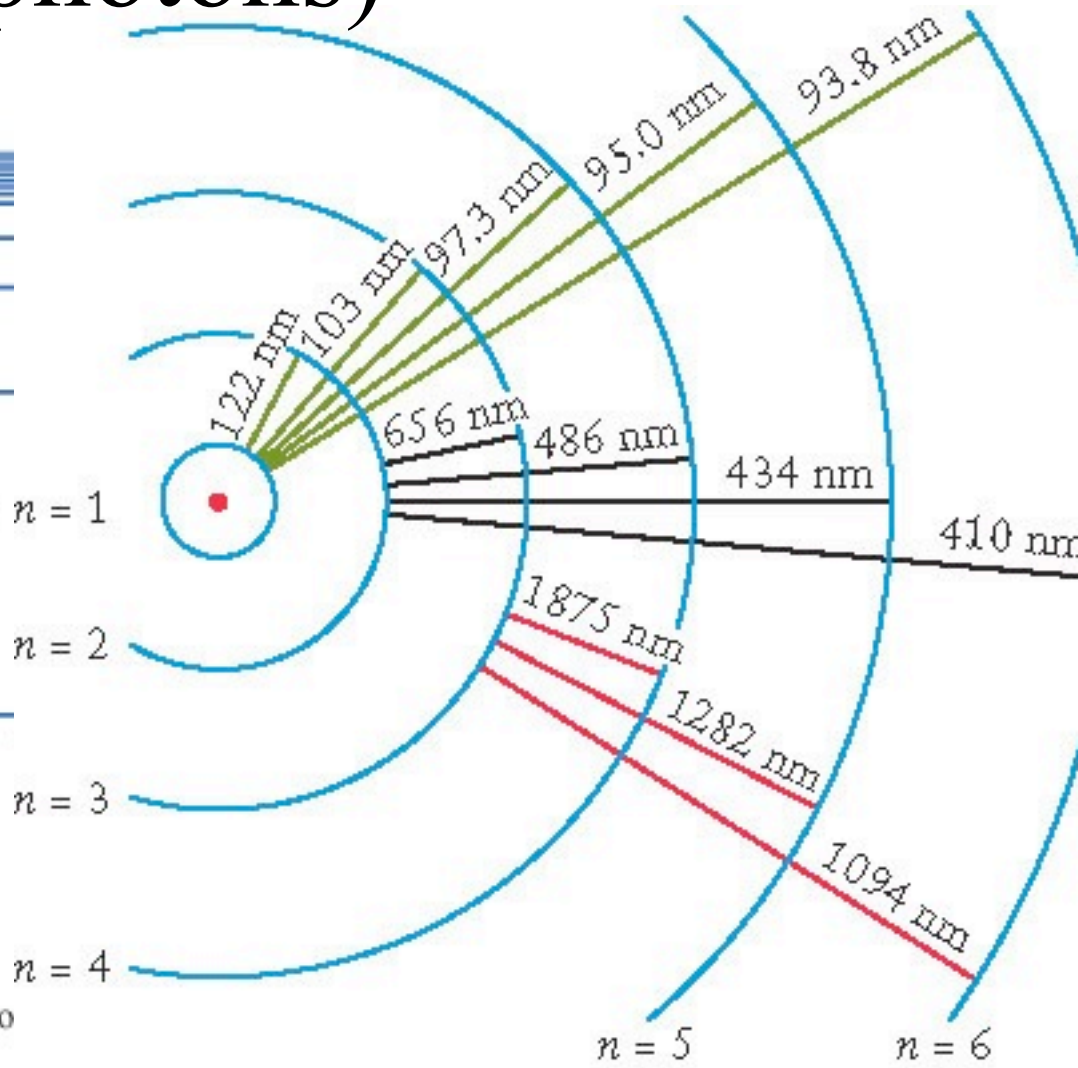




Energy levels of hydrogen

Transitions between orbits release energy (photons)

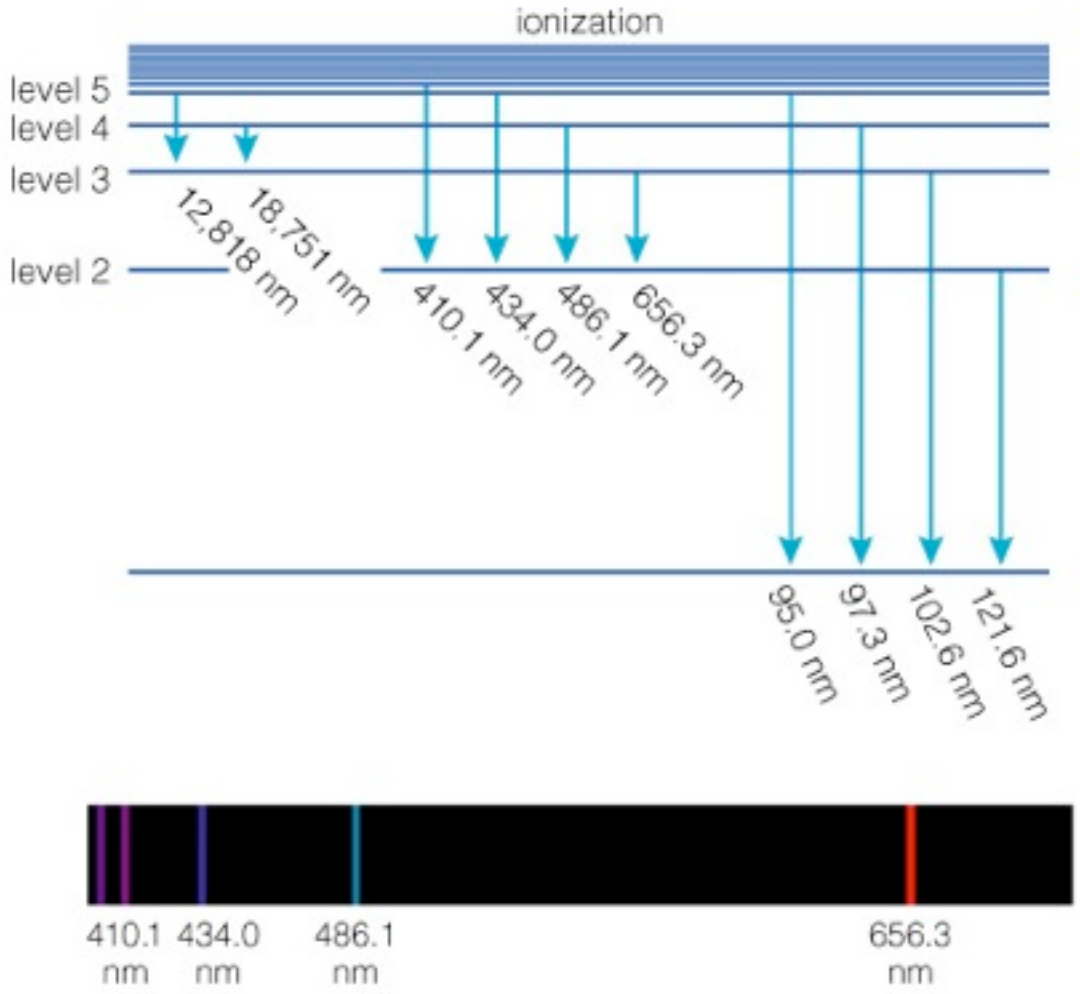


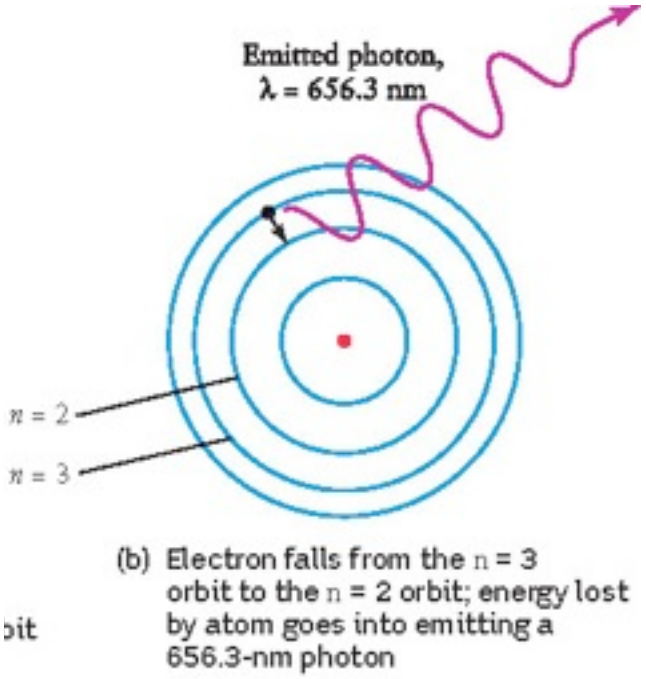


Energy levels of hydrogen

Chemical Fingerprints

- Downward transitions produce a unique pattern of emission lines.

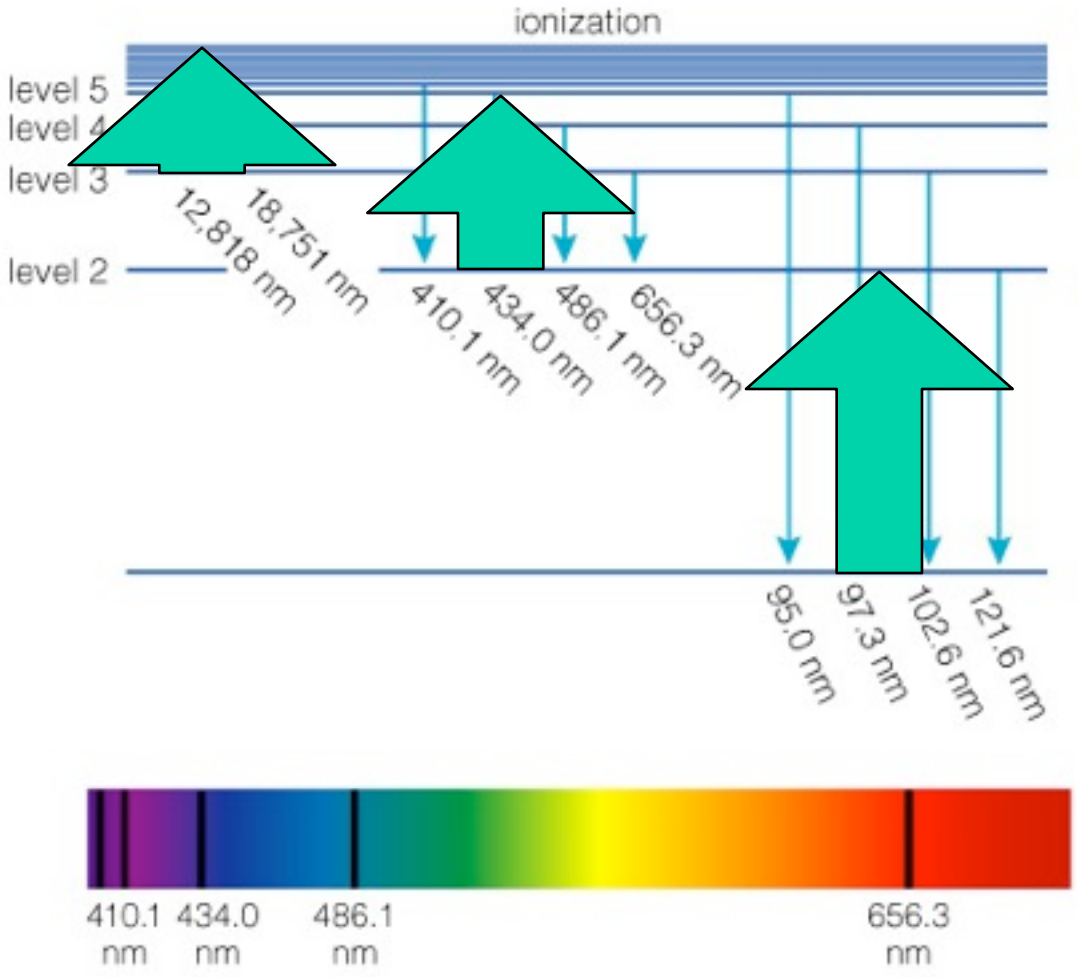


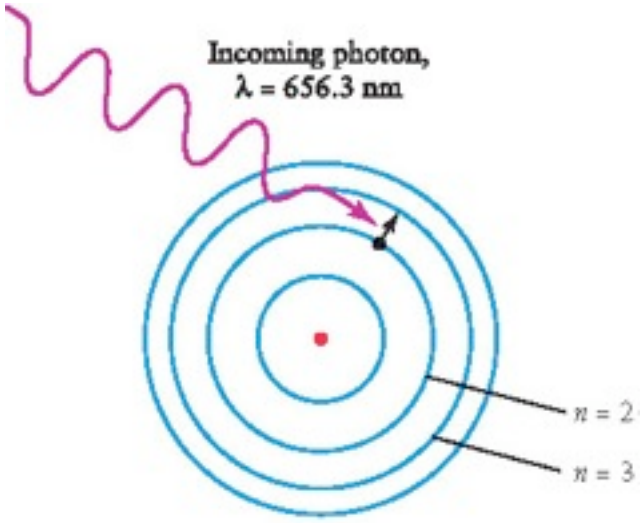


(b) Electron falls from the n = 3 orbit to the n = 2 orbit; energy lost by atom goes into emitting a 656.3-nm photon

Chemical Fingerprints

- Atoms can absorb photons with those same energies, so upward transitions produce absorption lines.



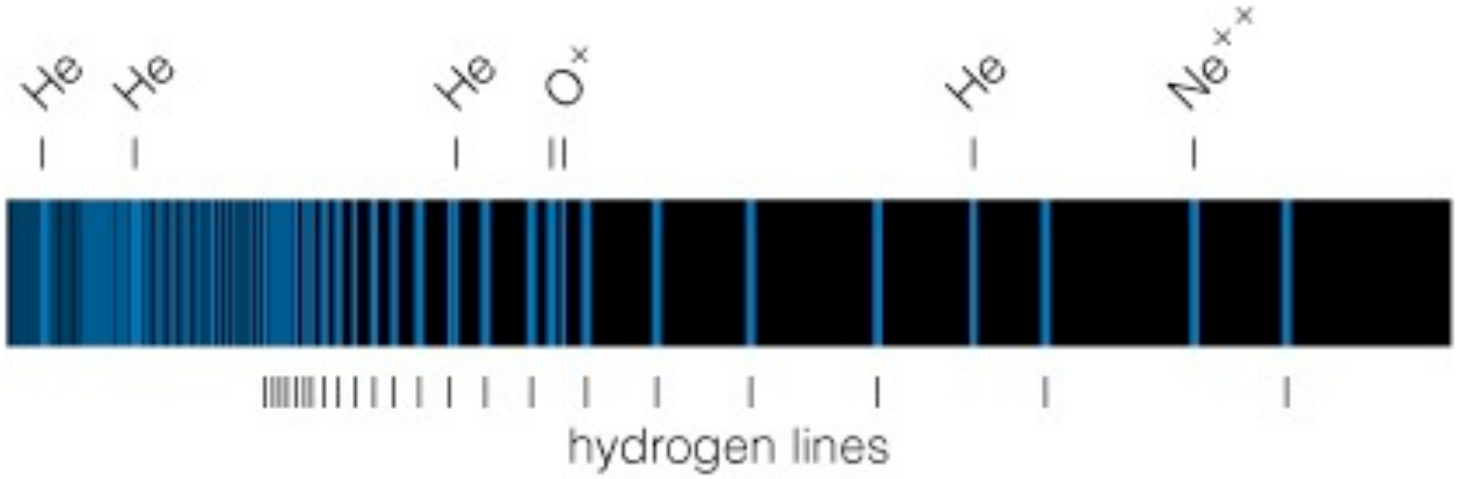


(a) Atom absorbs a 656.3-nm photon; absorbed energy causes electron to jump from the n = 2 orbit up the n = 3 orbit

Chemical Fingerprints

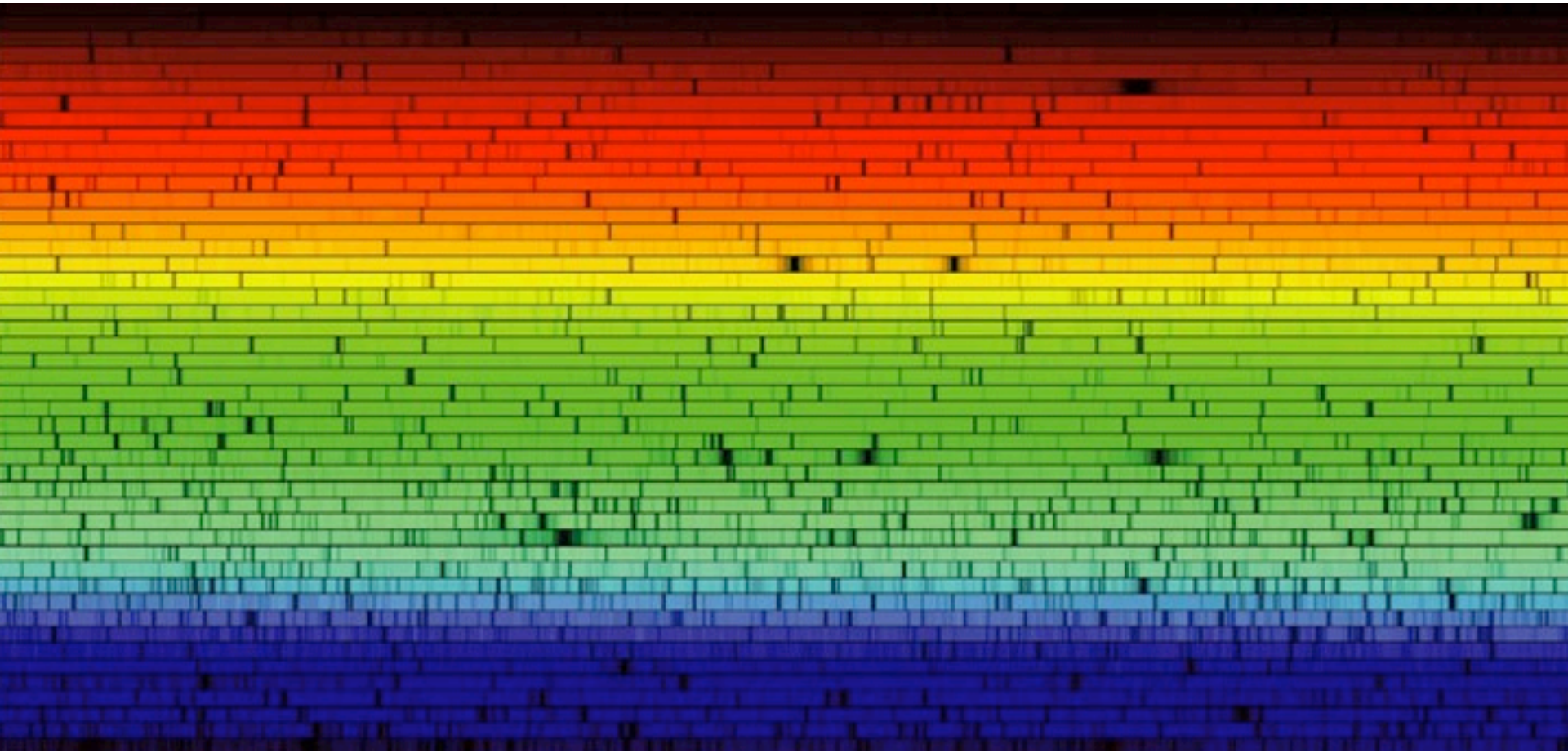
- Each type of atom has a unique spectral fingerprint.

Chemical Fingerprints



- Observing the fingerprints in a spectrum tells us which kinds of atoms are present.

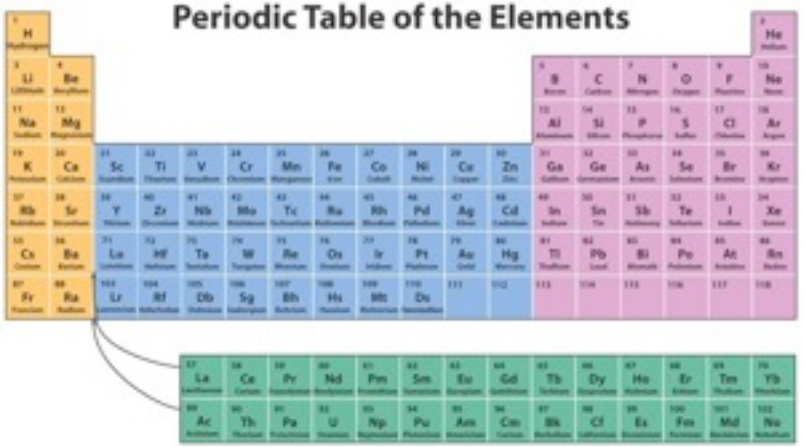
Example: Solar Spectrum



All the dark regions are absorption lines due to all the elements in the sun's atmosphere. The strengths of the lines tell us about the sun's composition and other physical properties.

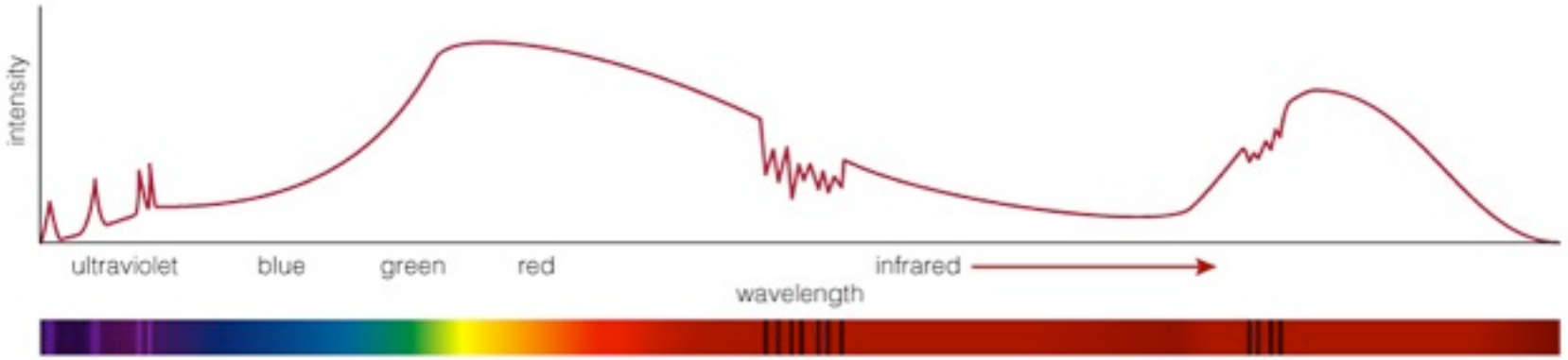
Solar composition

- 73% Hydrogen
- 25% Helium
- 2% everything else
  - "metals"



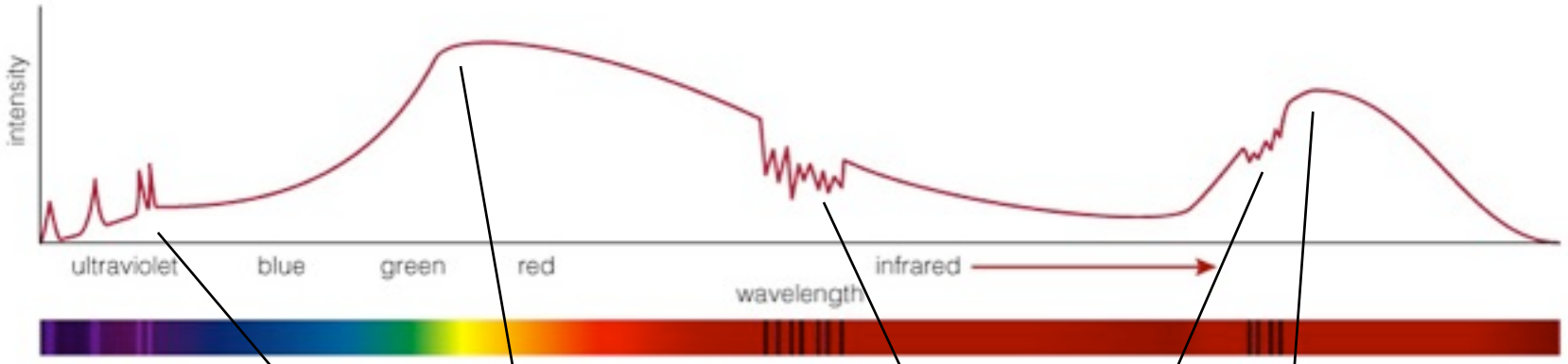
- Other stars similar
  - H & He most common stuff in the universe
  - Helium was *discovered* in the spectrum of the sun

Interpreting an Actual Spectrum



- By carefully studying the features in a spectrum, we can learn a great deal about the object that created it.

What is this object? Mars!



Hot upper atmosphere

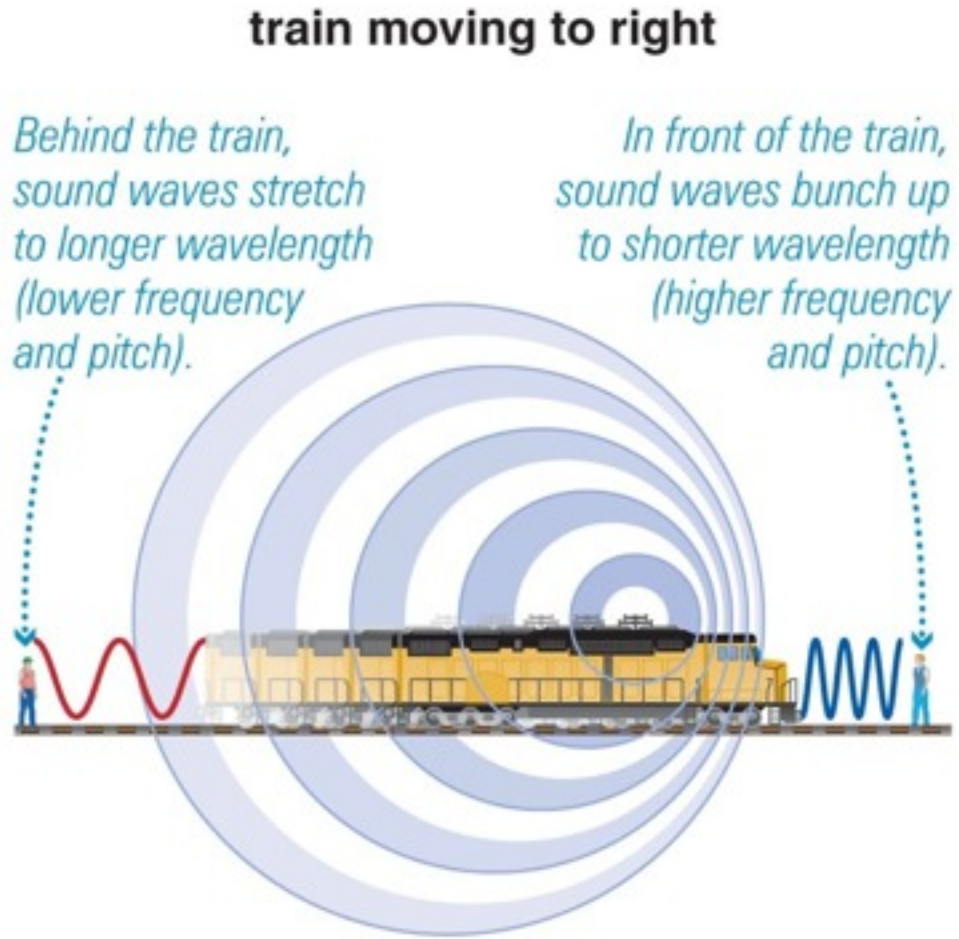
Reflected Sunlight:
Mars is red

Carbon Dioxide in atmosphere

Infrared peak
wavelength tells us
T = 225 K

We can learn an enormous amount from spectra!

The Doppler Effect



b For a moving train, the sound you hear depends on whether the train is moving toward you or away from you.

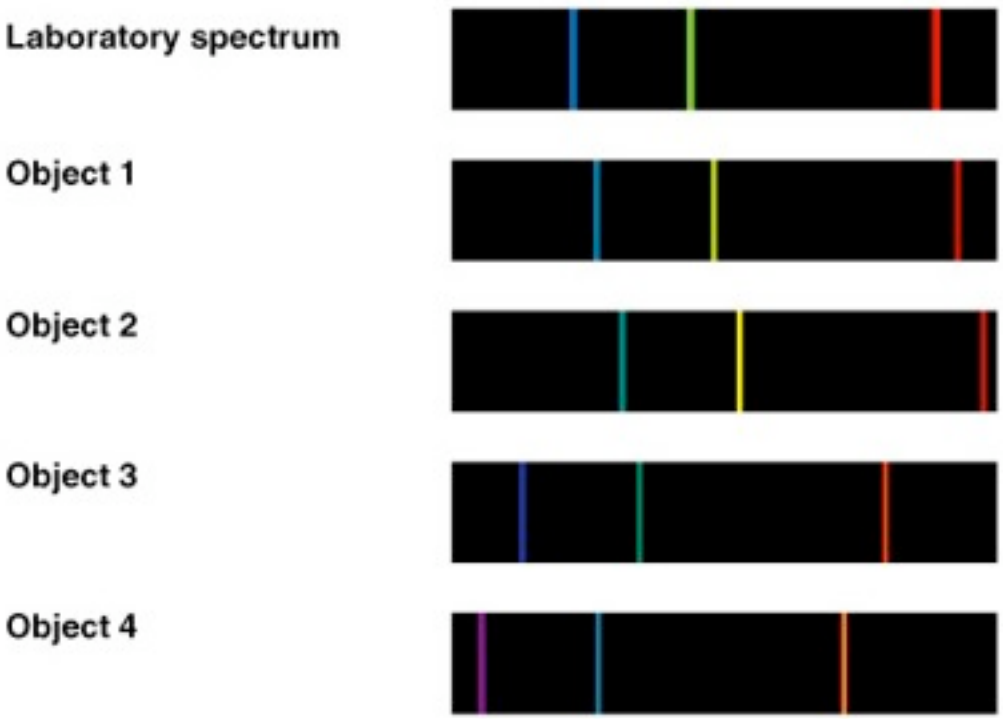
H2-41

Doppler Effect for Light

- Motion away -> redshift
- Motion towards -> blueshift

$$\frac{\Delta\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} = \frac{v}{c}$$

Measuring the Shift



Stationary

Moving Away

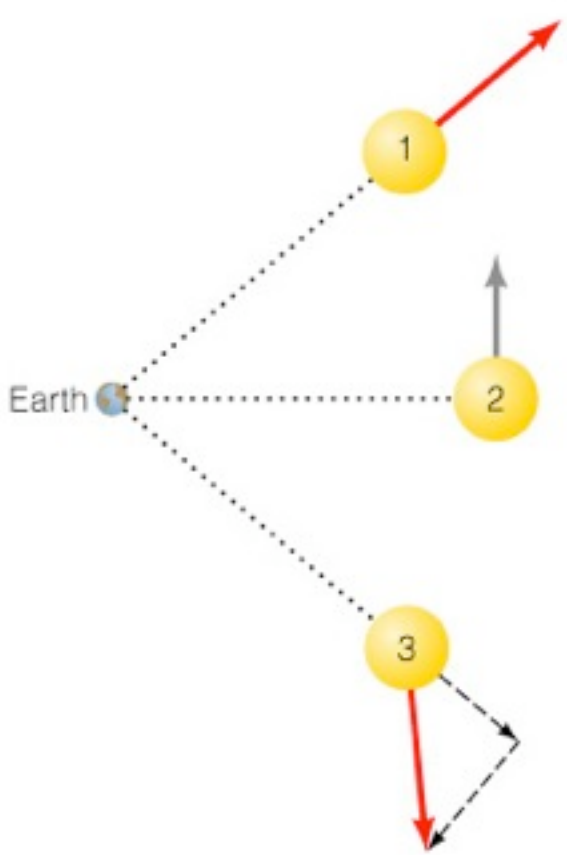
Away Faster

Moving Toward

Toward Faster

- We generally measure the Doppler effect from shifts in the wavelengths of spectral lines.

Doppler shift tells us ONLY about the part of an object's motion toward or away from us (along our line of sight).



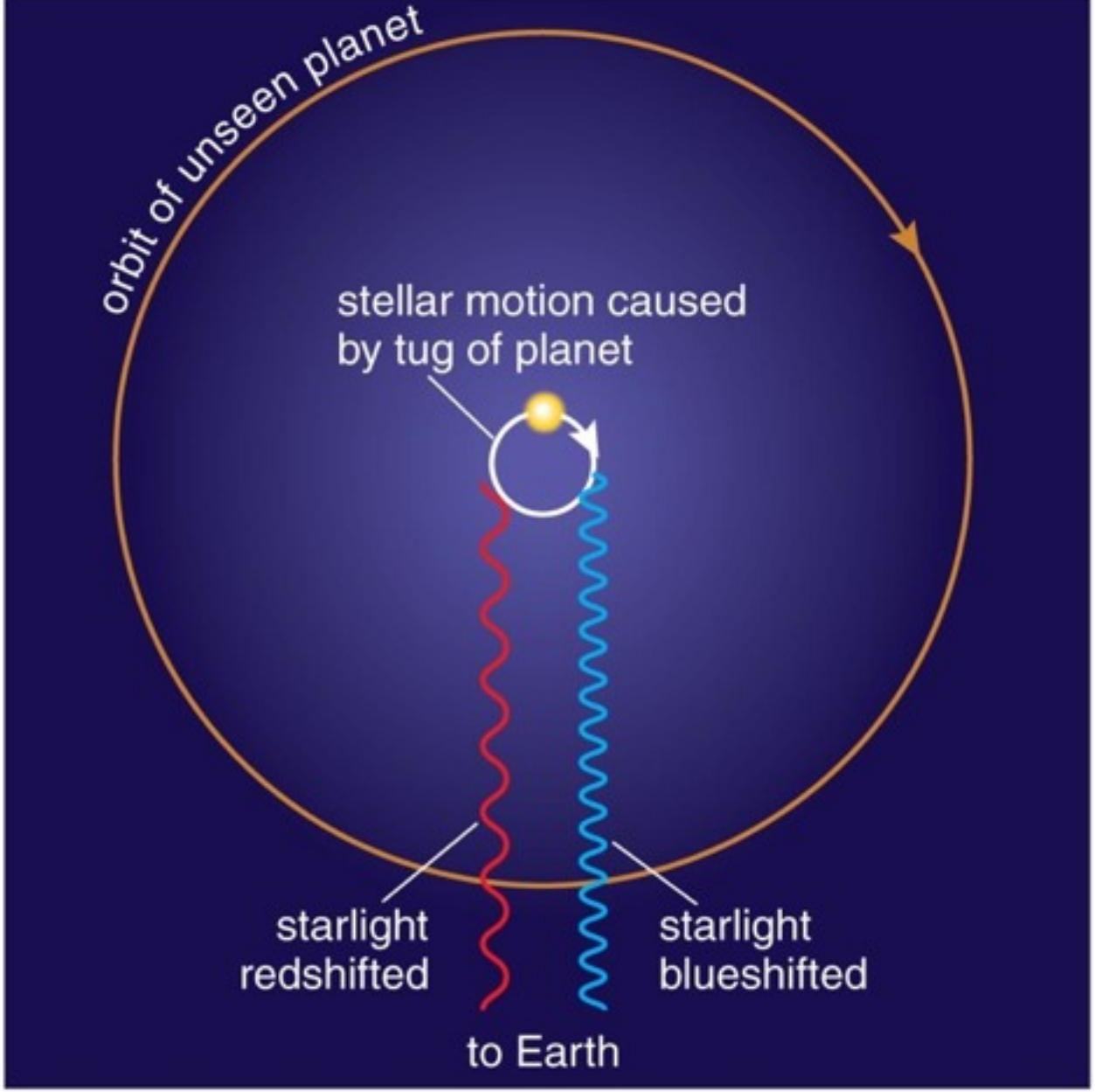
maximum doppler effect

no doppler effect

intermediate case

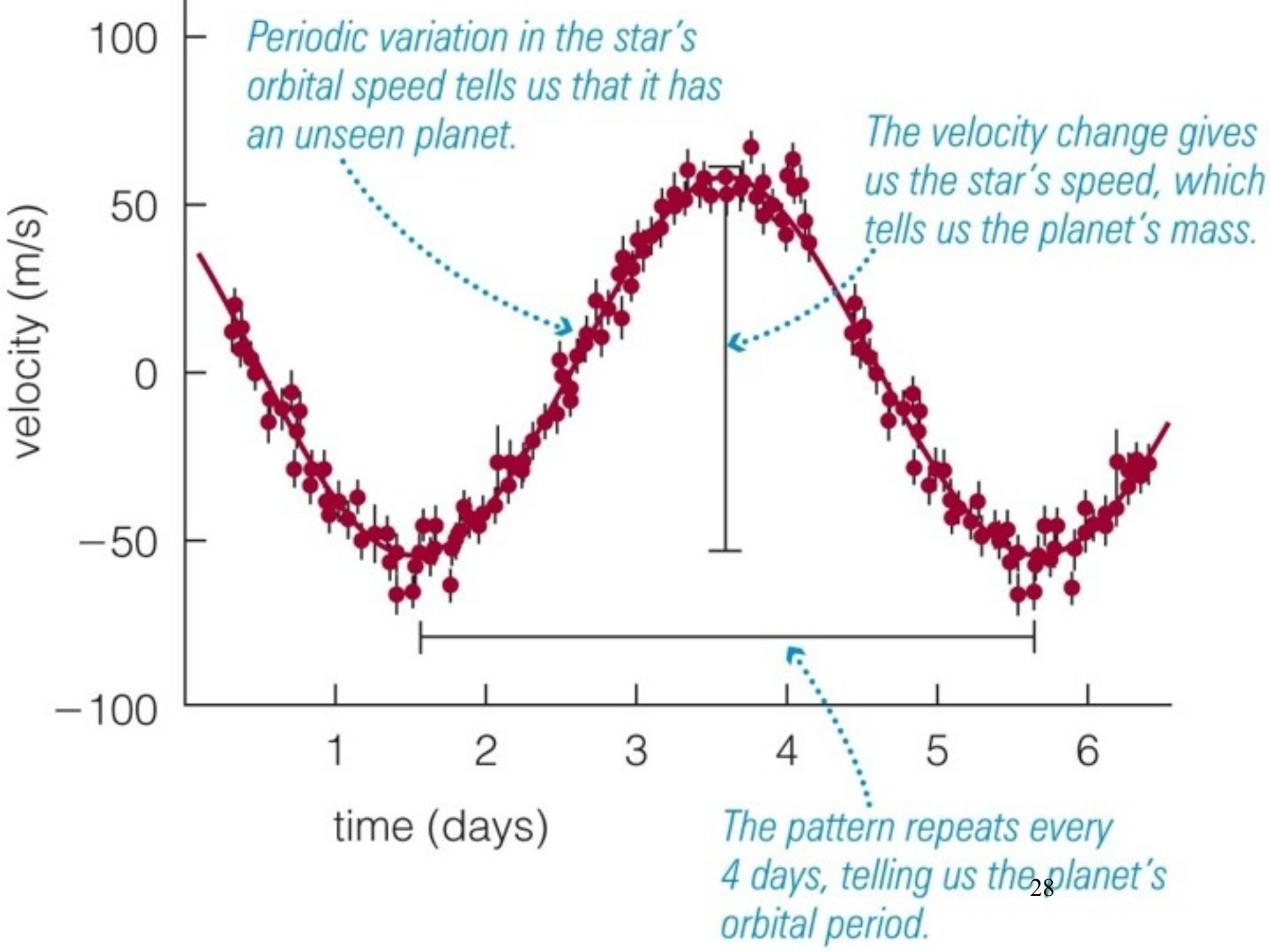
Doppler Application

- Extrasolar planets



C1-01

a Doppler shifts allow us to detect the slight motion of a star caused by an orbiting planet.


Periodic variation in the star's orbital speed tells us that it has an unseen planet.
The velocity change gives us the star's speed, which tells us the planet's mass.
The pattern repeats every 4 days, telling us the planet's orbital period.
velocity (m/s)
100
50
0
−50
−100
1
2
3
4
5
6
time (days)