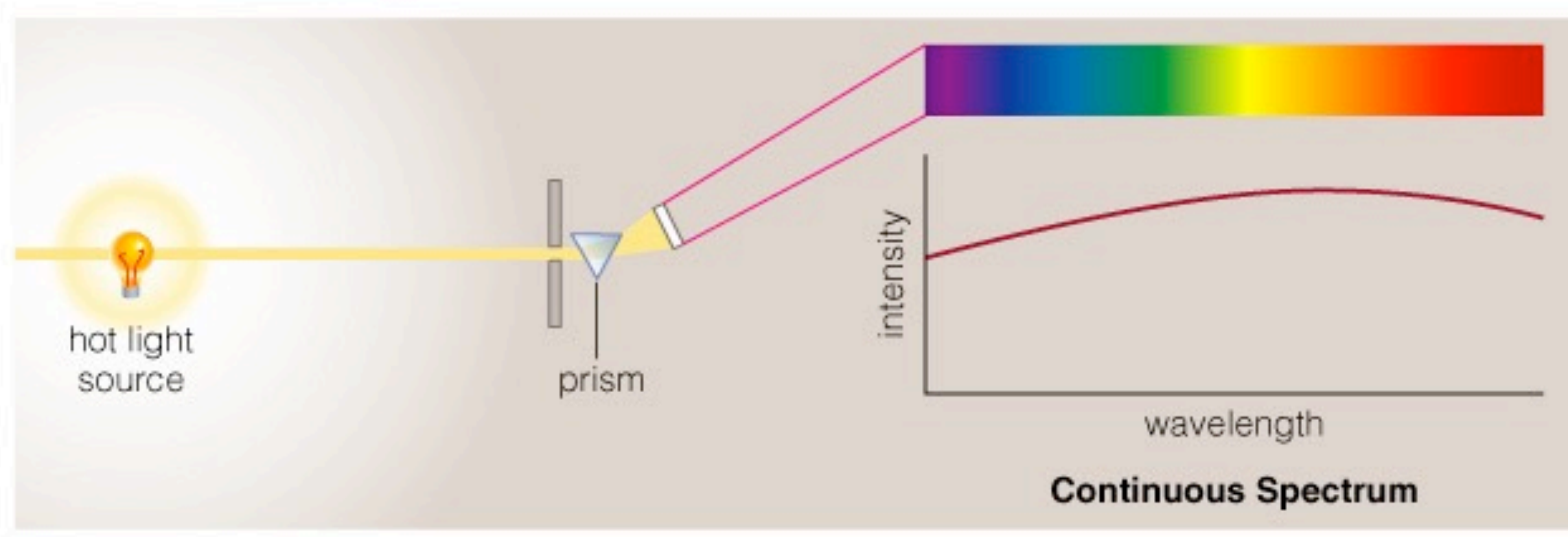
Today

- Kirchoff's Laws
- Doppler Effect & Motion
- Telescopes

Kirchoff's Laws

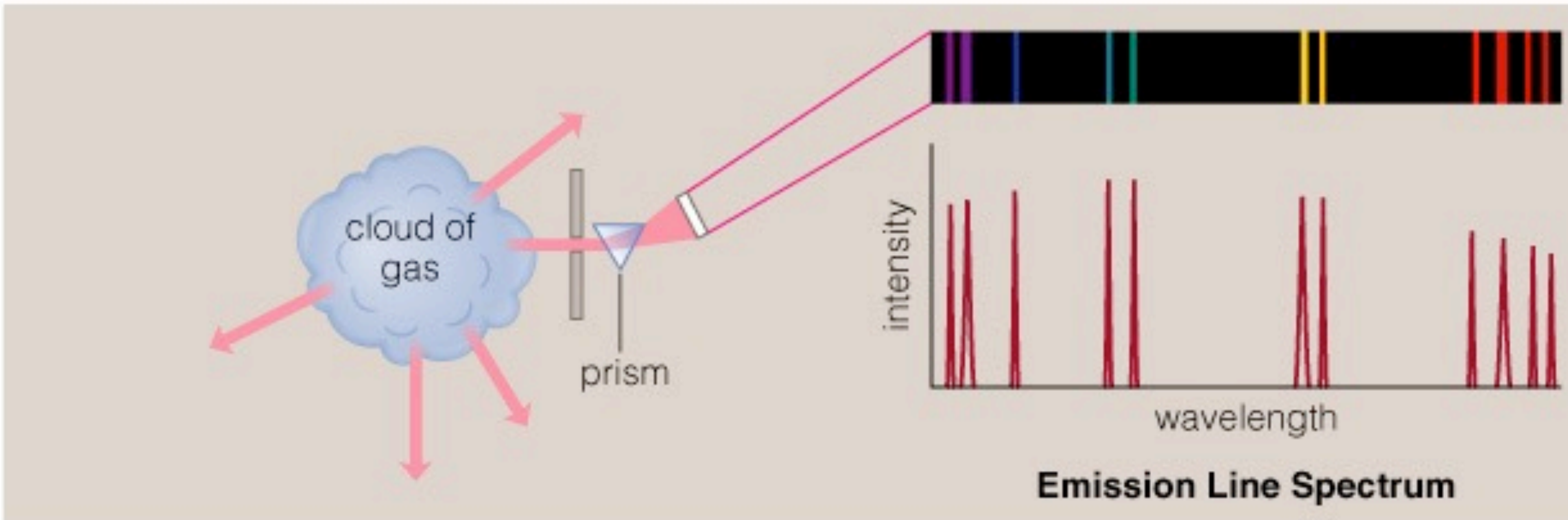
- Hot, dense objects emit a
  - **continuous spectrum** e.g., a light bulb
    - light of all colors & wavelengths
    - follows thermal distribution
    - obeys Wien's & Steffan-Boltzmann Laws.
- Hot, diffuse gas emits light only at specific wavelengths.
  - **emission line spectrum** e.g., a neon light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

Continuous Spectrum



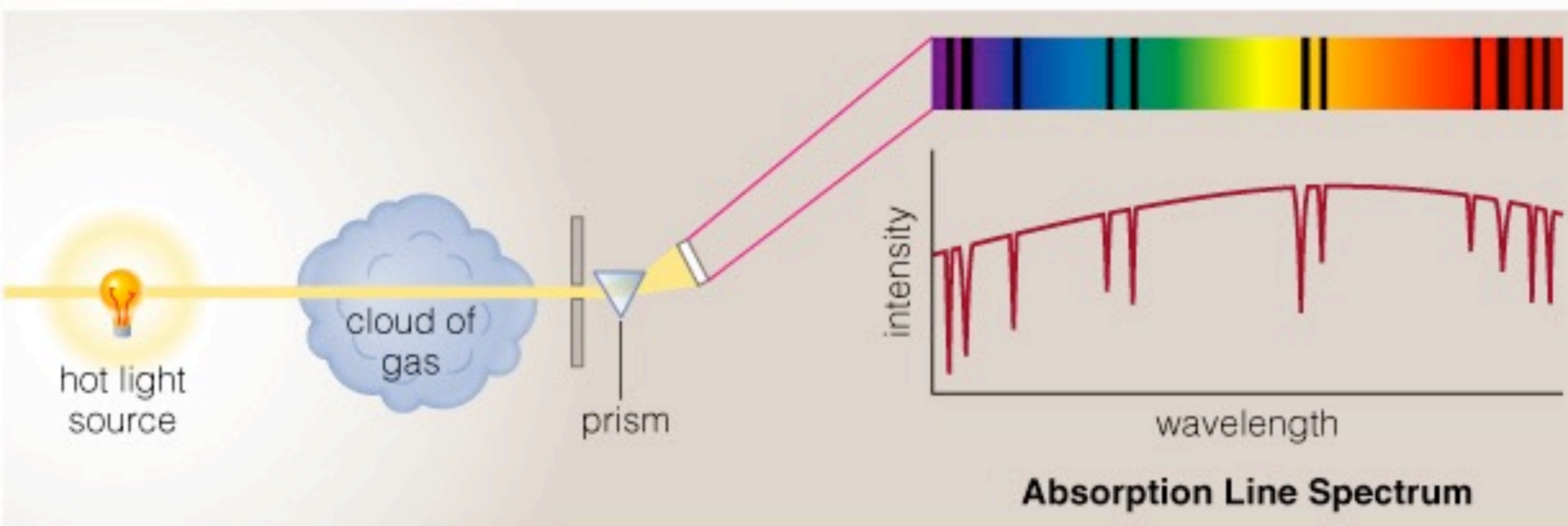
- The spectrum of a common (incandescent) light bulb spans all visible wavelengths, without interruption.

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.

Kirchoff's Laws

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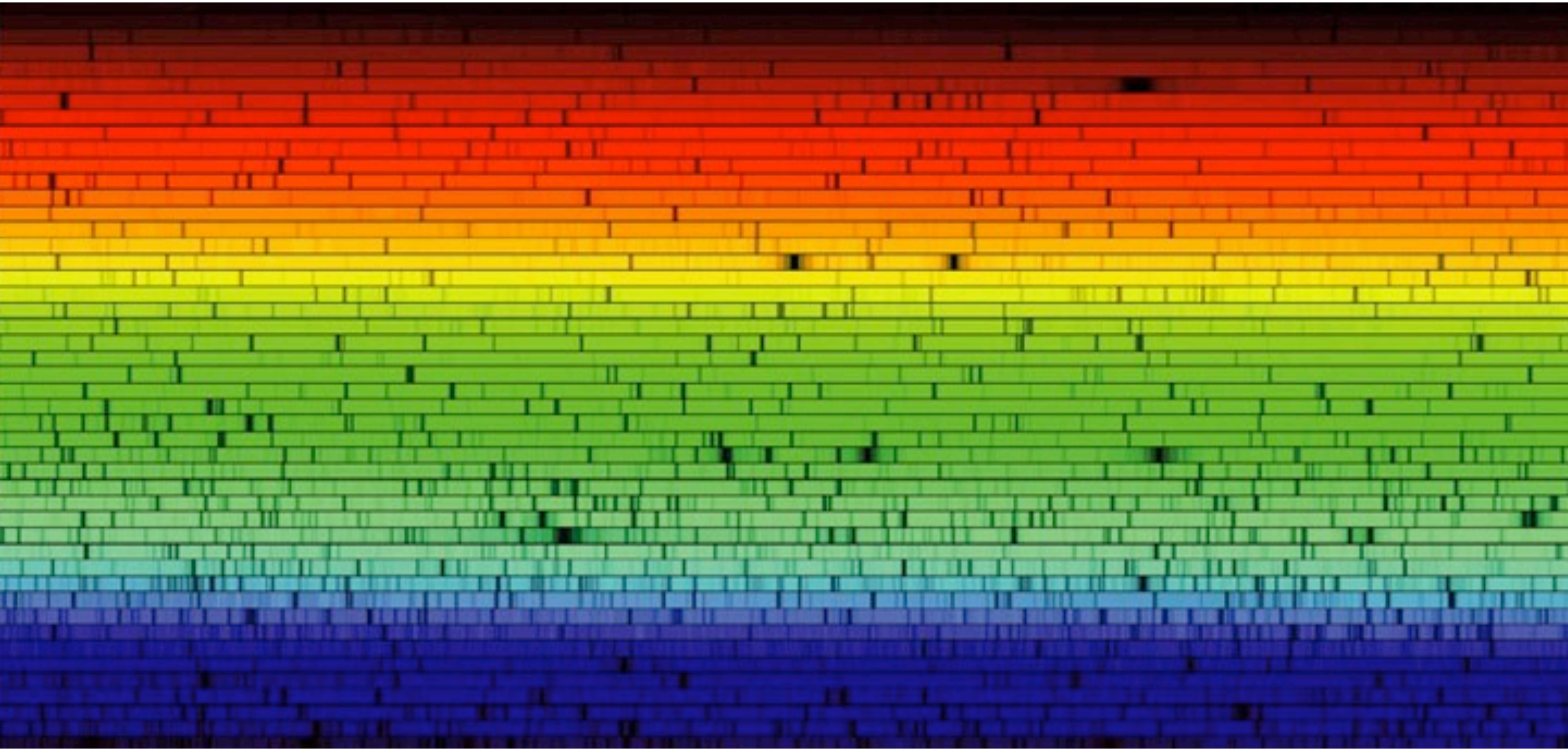
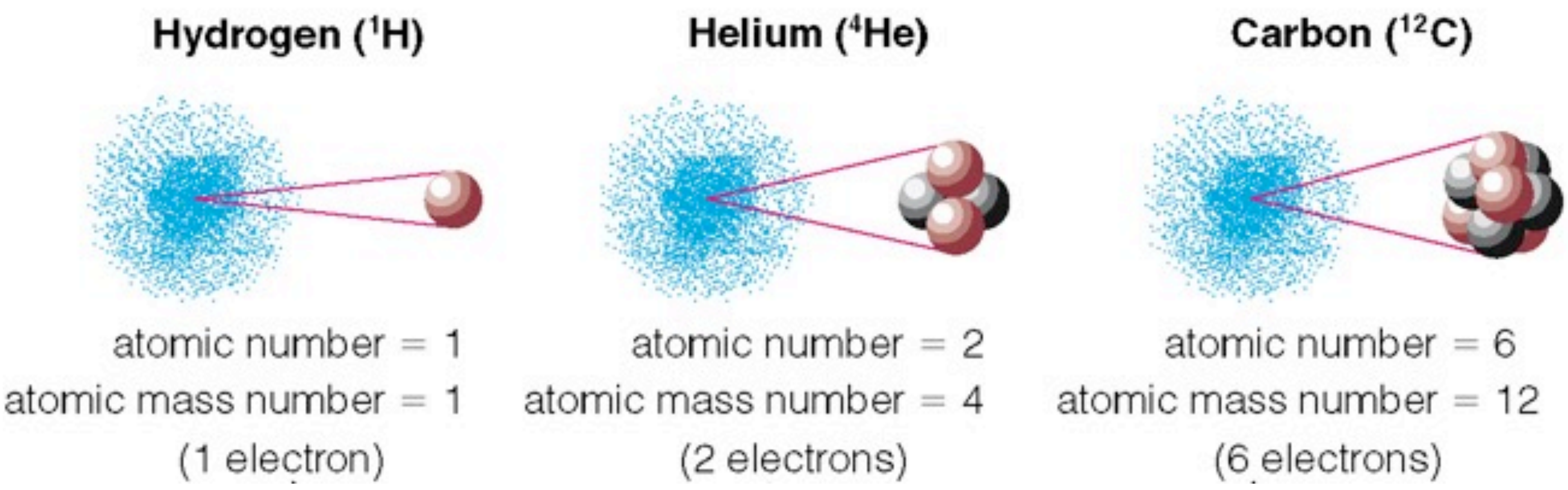
How does light tell us what things are made of?



Spectrum of the Sun

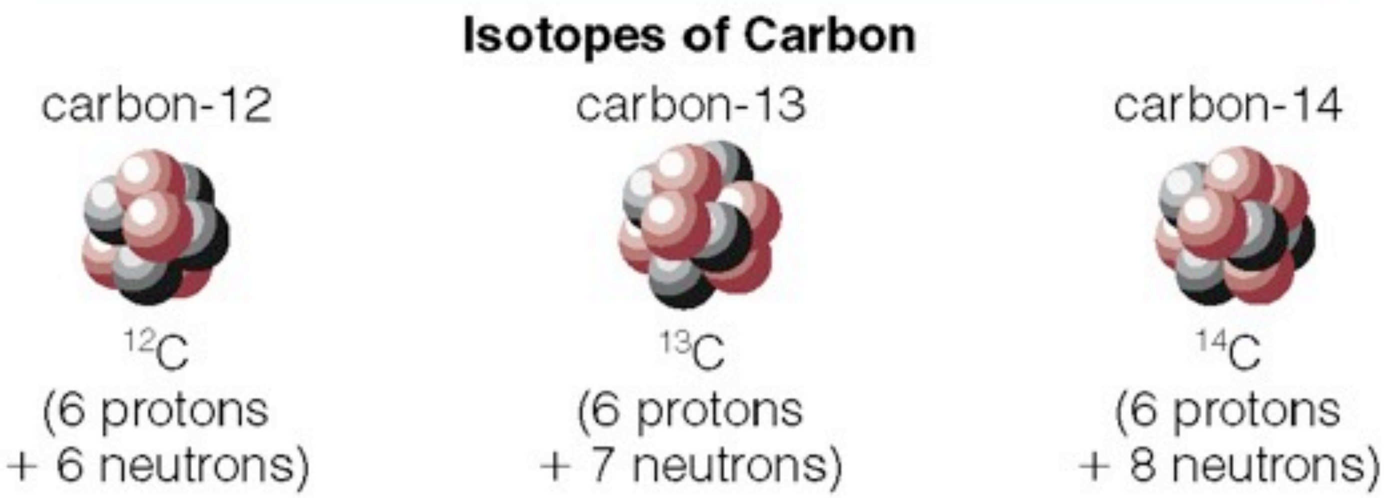
Atomic Terminology

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



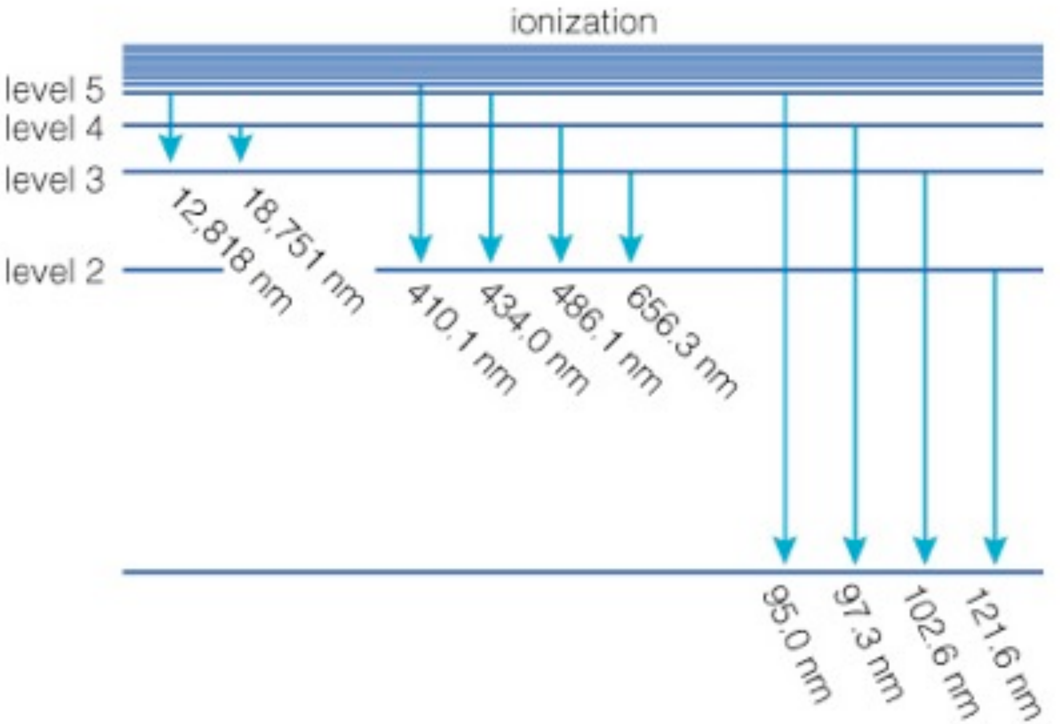
Atomic Terminology

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



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

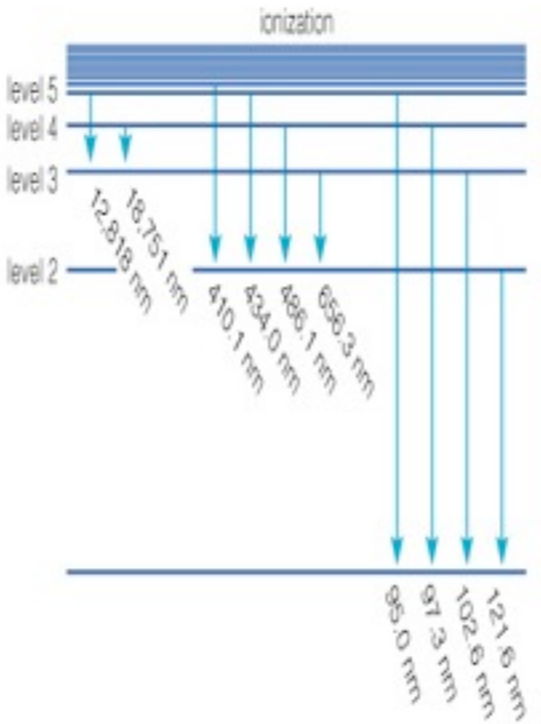
Chemical Fingerprints

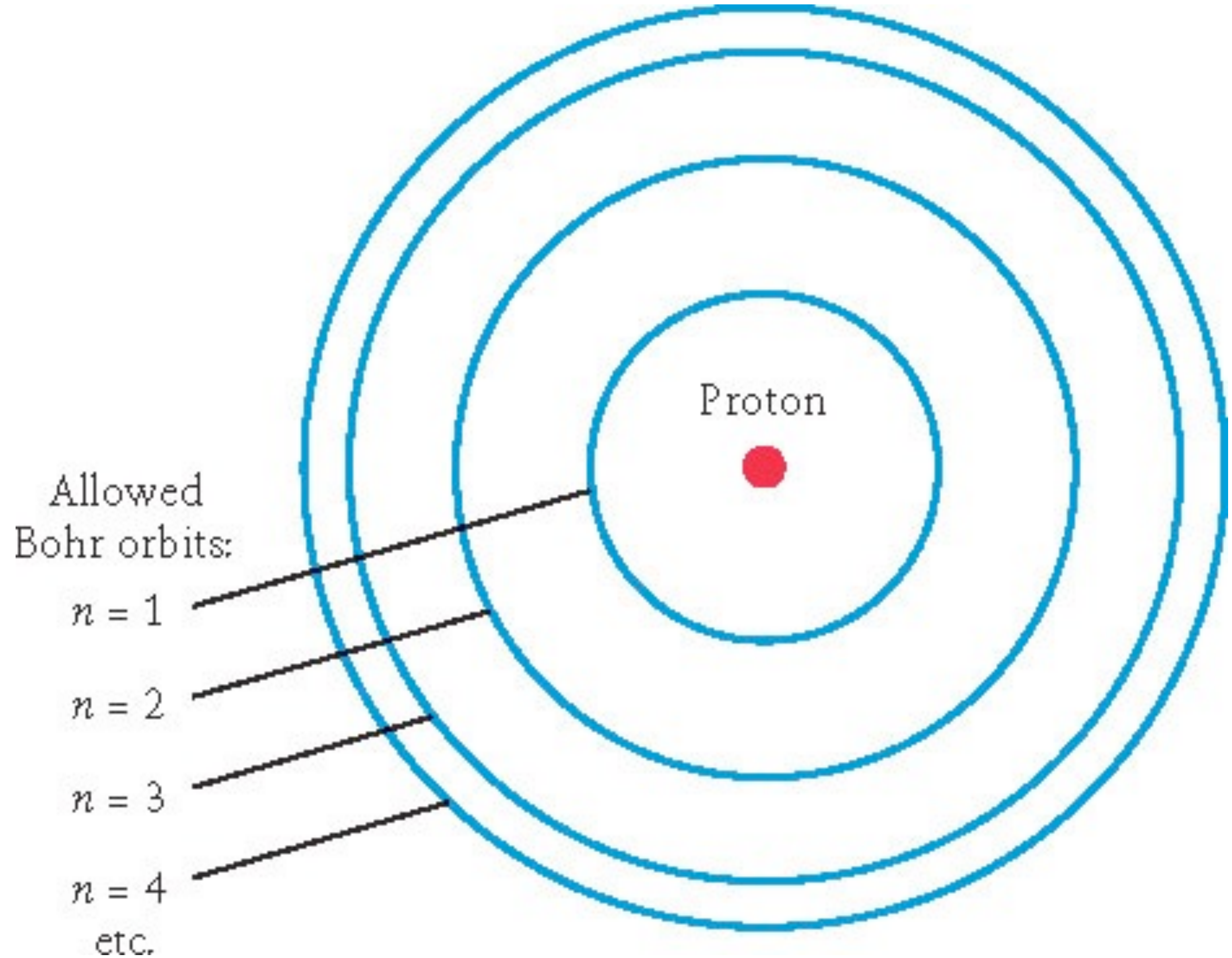


Energy levels of hydrogen

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

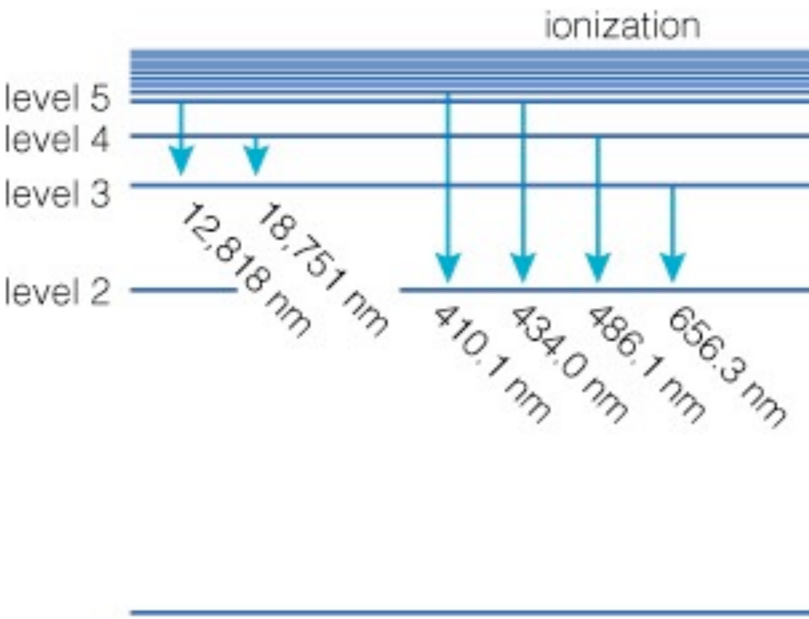
Possible Electron orbits

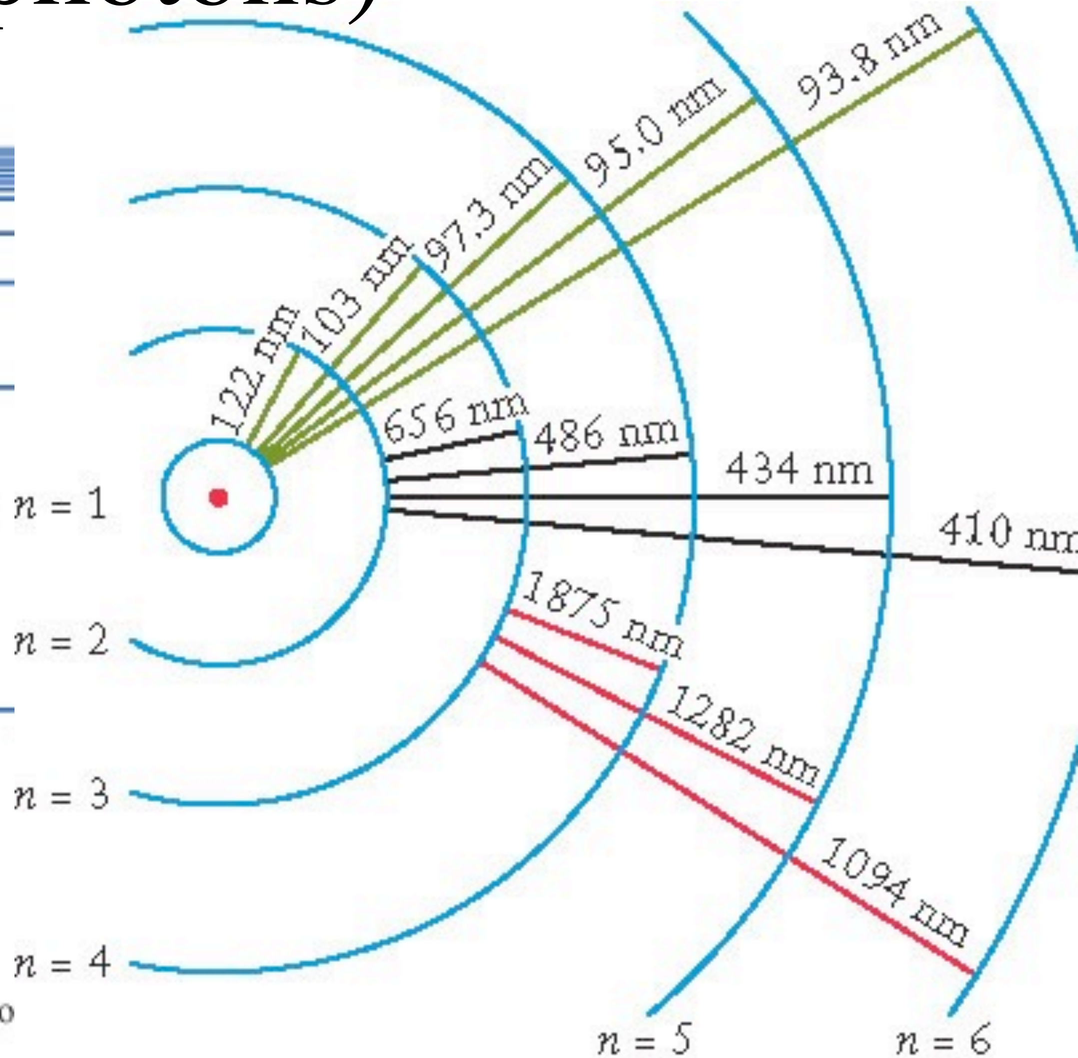




Energy levels of hydrogen

Transitions between orbits release energy (photons)

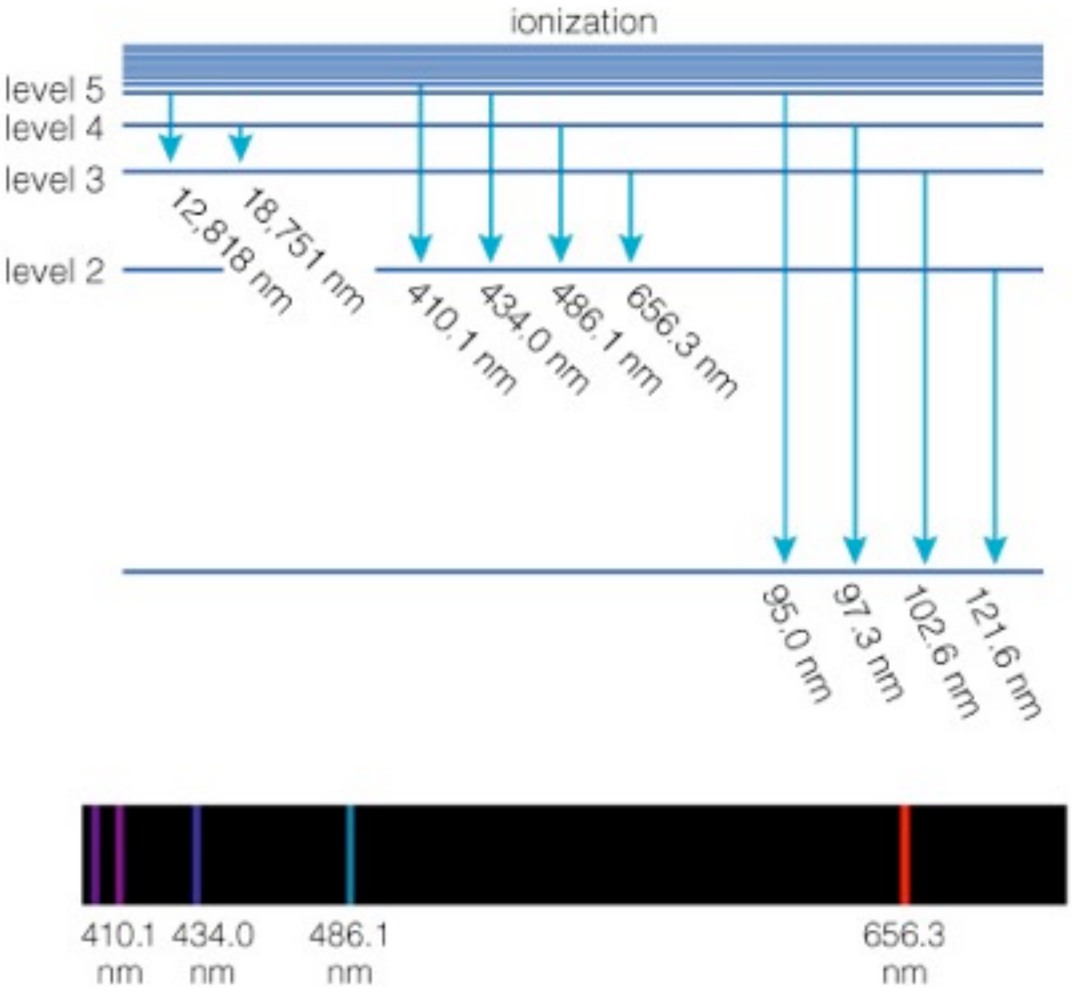


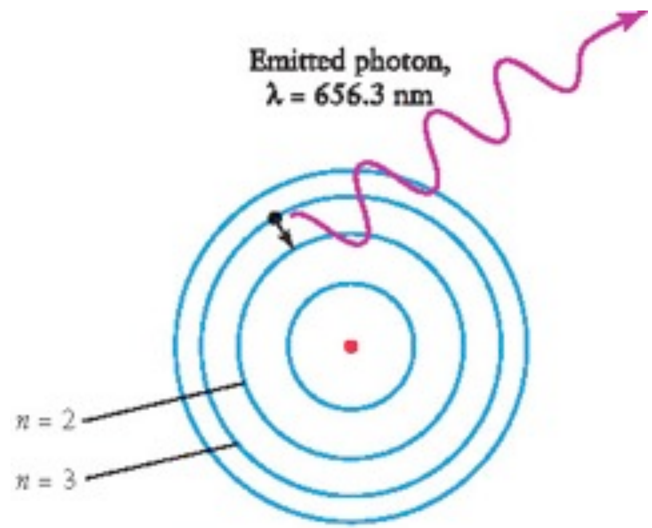


Energy levels of hydrogen

Chemical Fingerprints

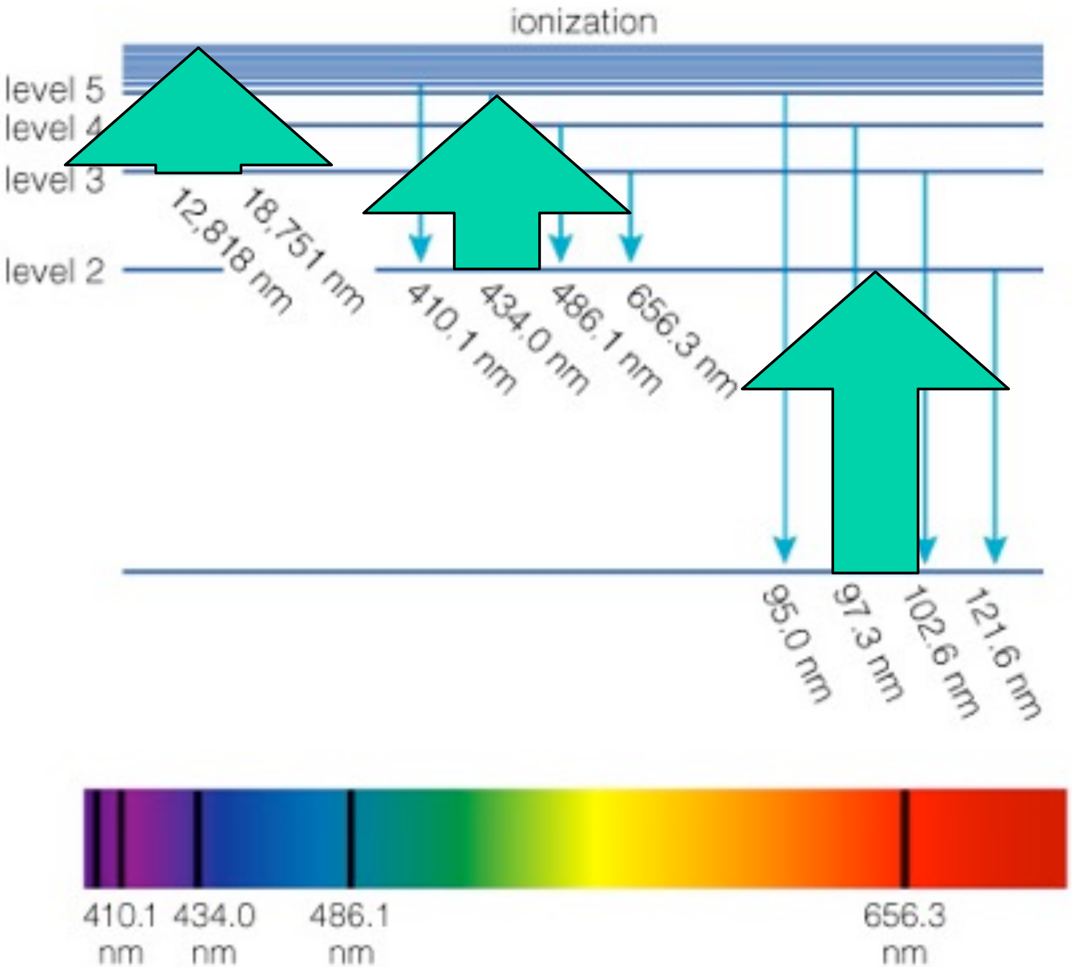
- Downward transitions produce a unique pattern of emission lines.



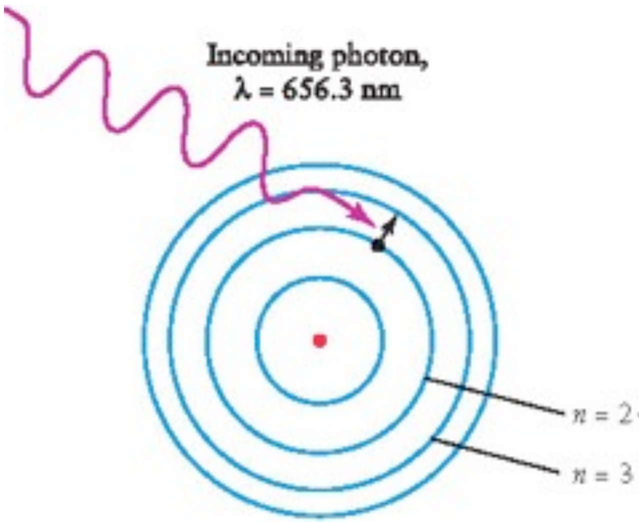


(b) Electron falls from the n = 3 orbit to the n = 2 orbit; energy lost by atom goes into emitting a 656.3-nm photon

Chemical Fingerprints



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

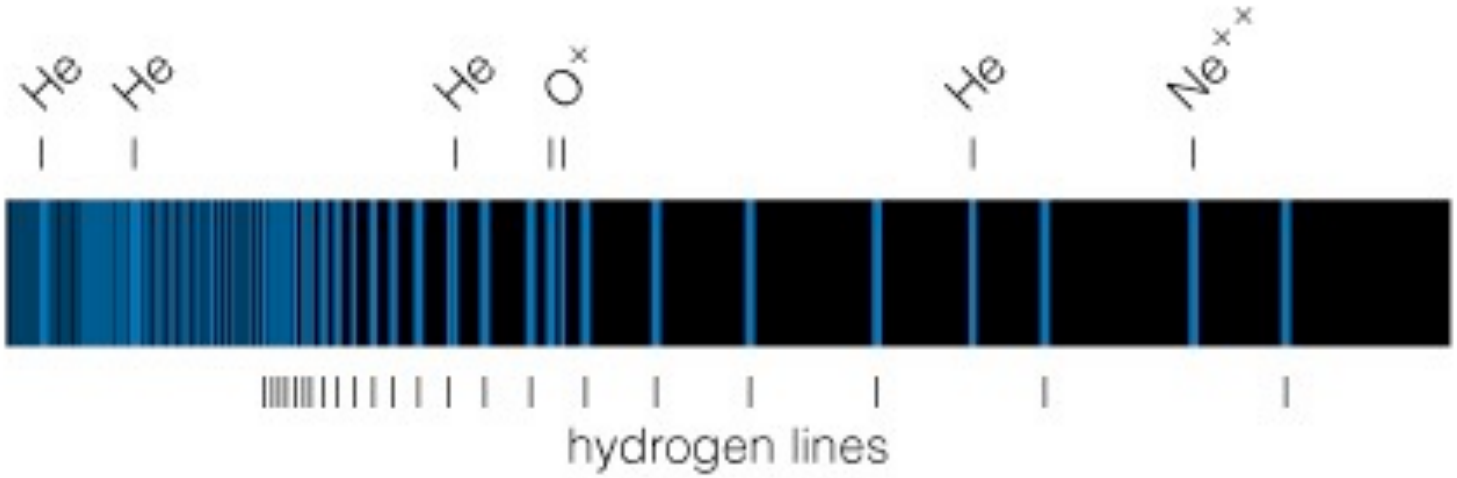


(a) Atom absorbs a 656.3-nm photon; absorbed energy causes electron to jump from the n = 2 orbit up the n = 3 orbit

Chemical Fingerprints

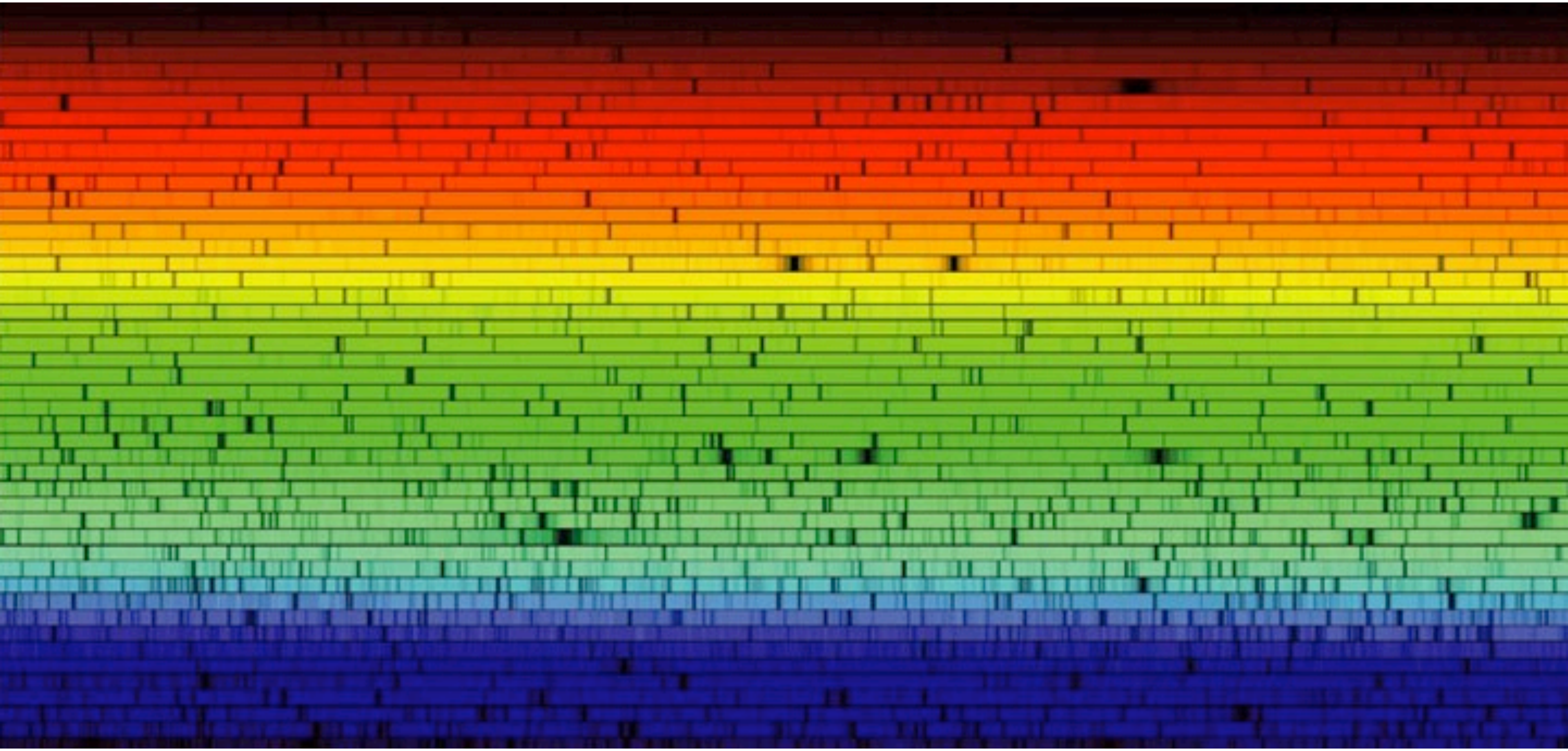
- Each type of atom has a unique spectral fingerprint.

Chemical Fingerprints



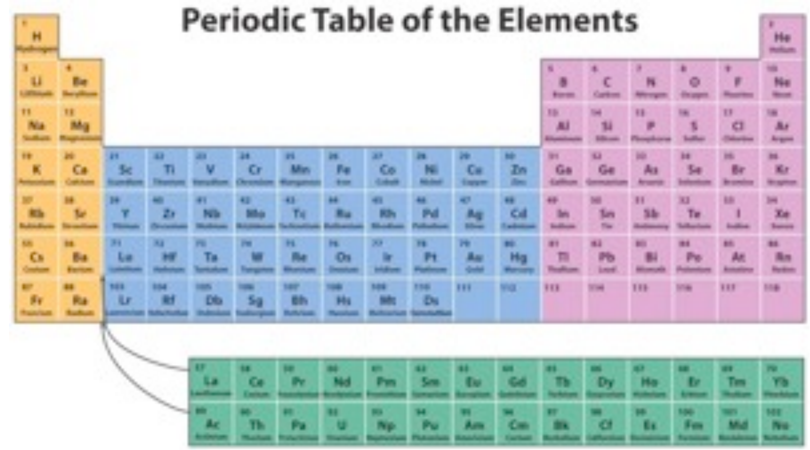
- Observing the fingerprints in a spectrum tells us which kinds of atoms are present.

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.

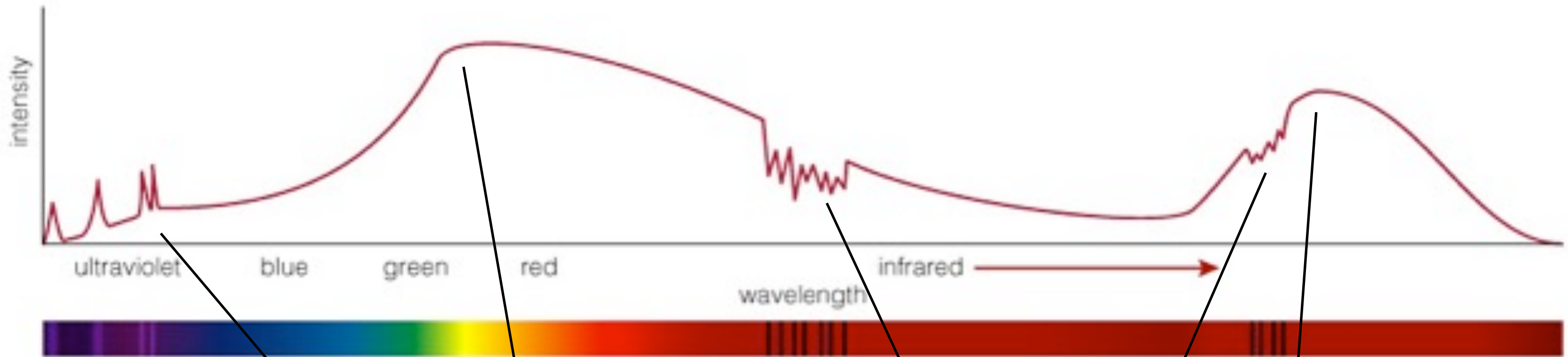
Solar composition



- 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

What is this object? Mars!



Hot upper atmosphere

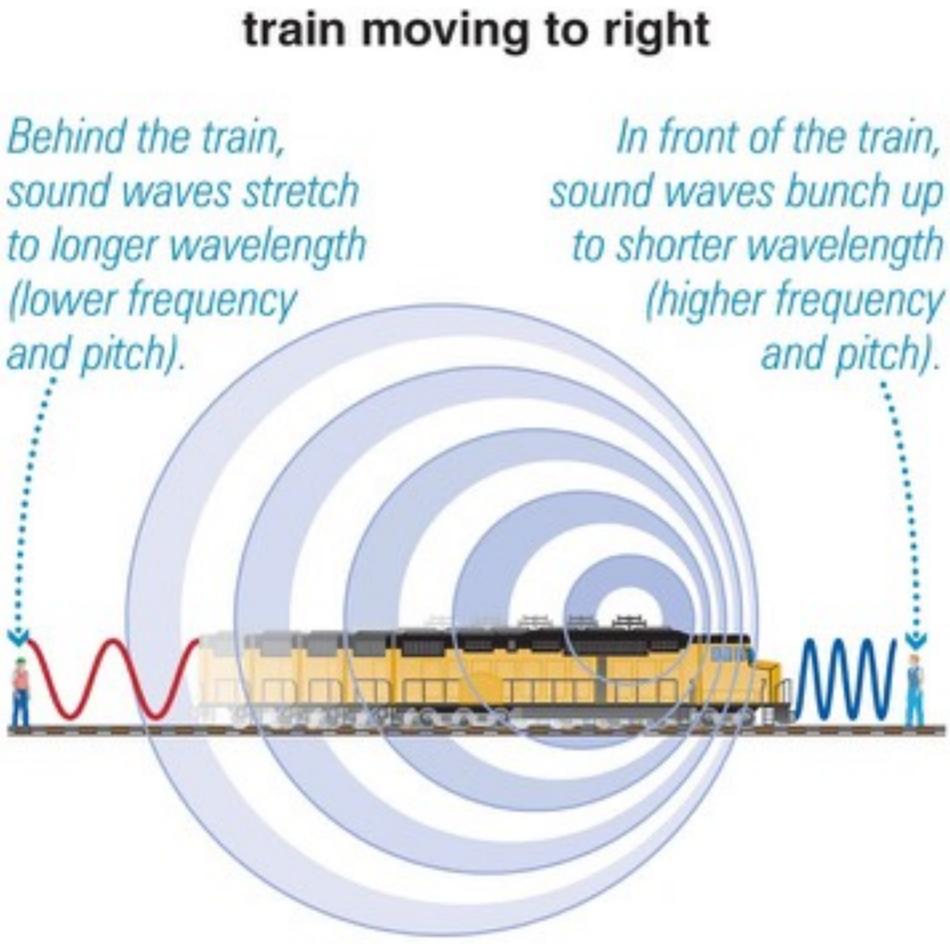
Carbon Dioxide in atmosphere

Reflected Sunlight:
Mars is red

Infrared peak
wavelength tells us
T = 225 K

We can learn an enormous amount from spectra:
temperature, density, and composition

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.

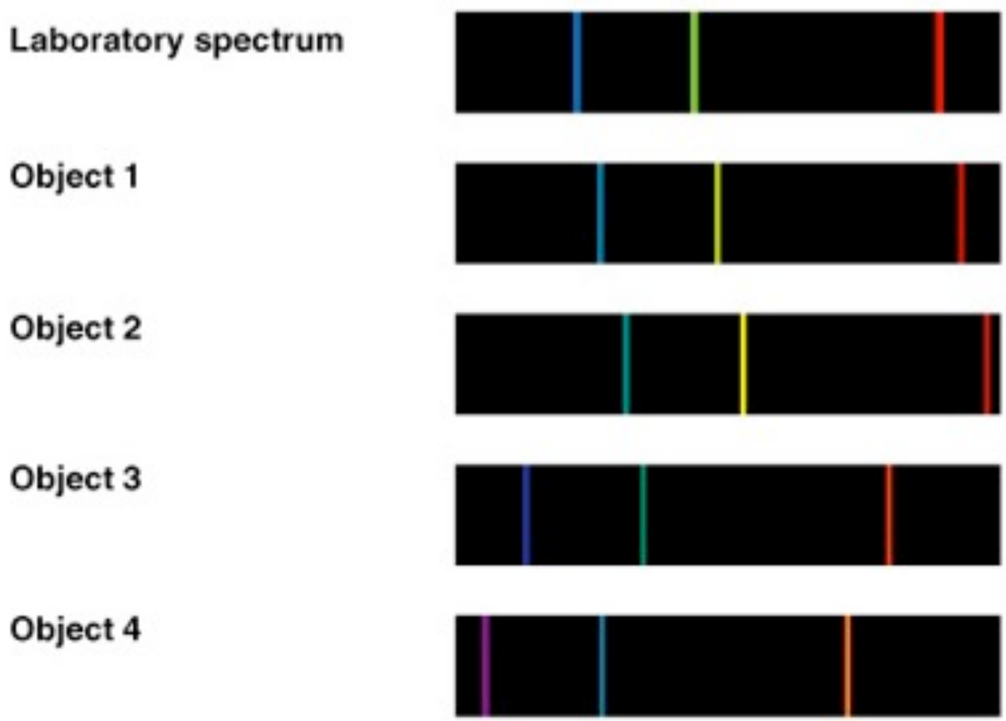
Doppler ball

Doppler Effect for Light

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

$$\frac{\text{wavelength shift}}{\text{wavelength}} \quad \frac{\Delta\lambda}{\lambda} = \frac{\lambda_{obs} - \lambda_{em}}{\lambda_{em}} = \frac{v}{c} \quad \frac{\text{speed}}{\text{speed of light}}$$

Measuring the Shift



Stationary

Moving Away

Away Faster

redshift

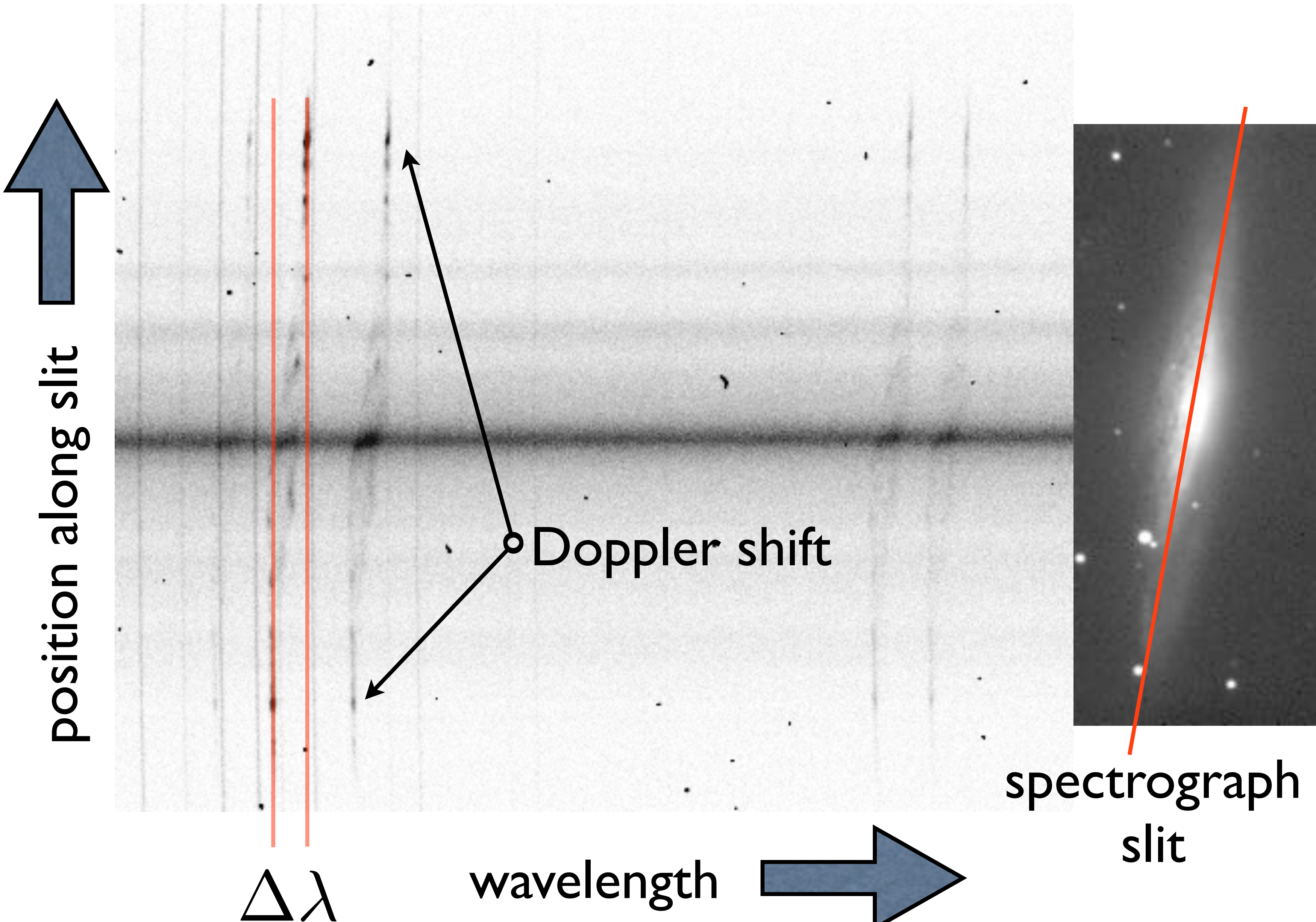
Moving Toward

Toward Faster

blueshift

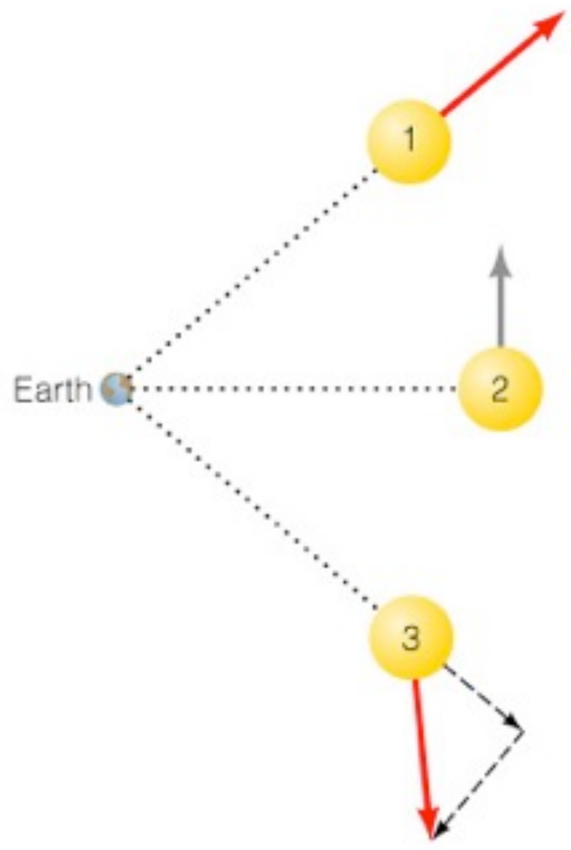
- We generally measure the Doppler effect from shifts in the wavelengths of spectral lines.

Spectrum



position along slit
Doppler shift
spectrograph
slit
Δλ
wavelength

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

Telescopes

- Telescopes collect more light than our eyes ⇒ **light-collecting area**
- Telescopes can see more detail than our eyes ⇒ **angular resolution** (magnification)
- Telescopes/instruments can record light more sensitively than our eyes, and detect electromagnetic radiation that is invisible to our eyes (e.g., infrared, ultraviolet)

Bigger is better

1. Larger light-collecting area

   can see fainter things

2. Better angular resolution

   can see smaller things

Bigger is better

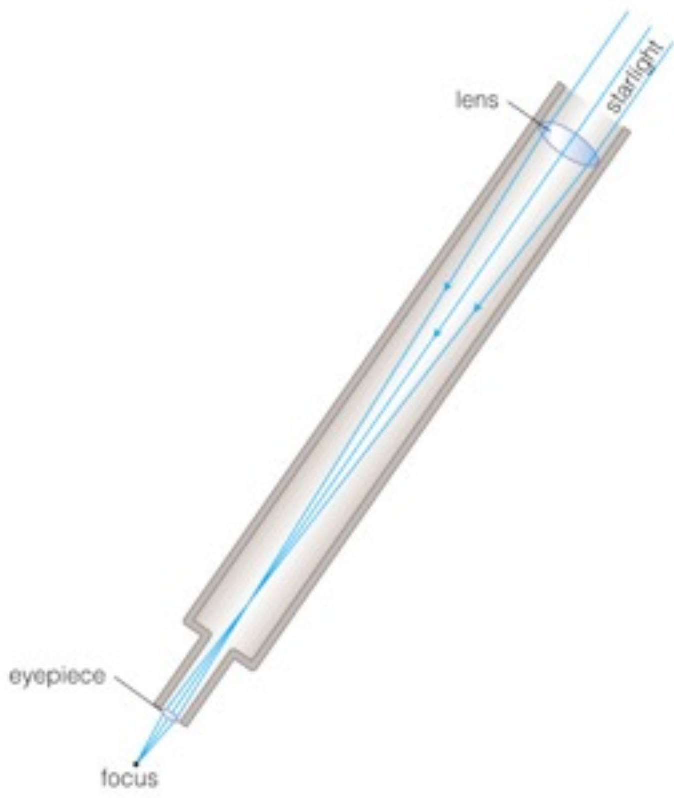
For a telescope with mirror of diameter D,

can see fainter: $$b^{-1} \propto D^2$$

with higher resolution: $$\theta \propto \frac{\lambda}{D}$$

Basic Telescope Design

- Refracting: lenses

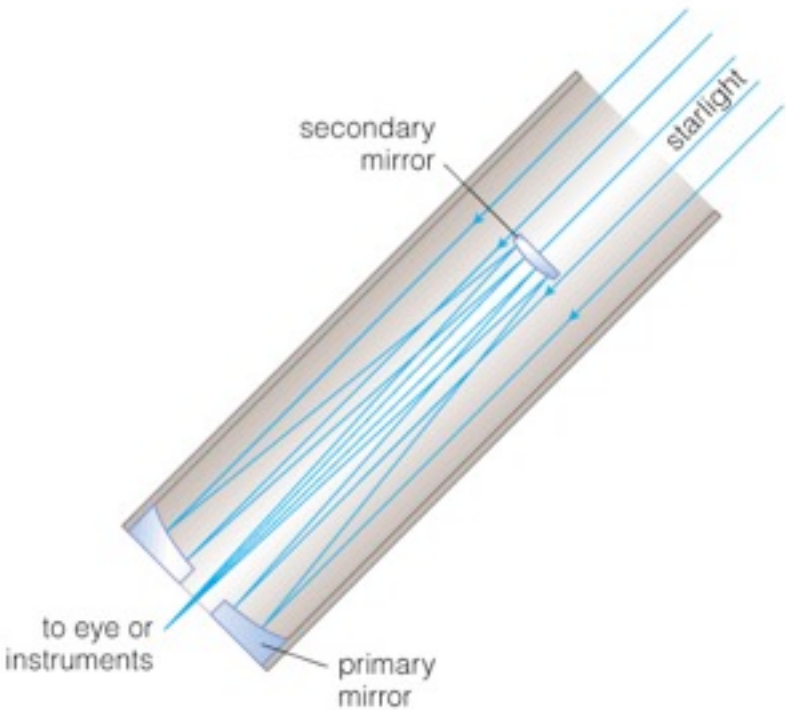


Refracting telescope

Yerkes 1-m refractor

Basic Telescope Design

- Reflecting: mirrors
- Most research telescopes today are reflectors



Reflecting telescope

Gemini North 8-m

Kitt Peak National Observatory (AZ)

4 m


2.1 m
Burrell
Schmidt
WIYN (3.5 m)

Different designs for different wavelengths of light

Radio telescope (Arecibo, Puerto Rico)

Longer wavelengths need larger "mirrors"

FAST 500 m (China)