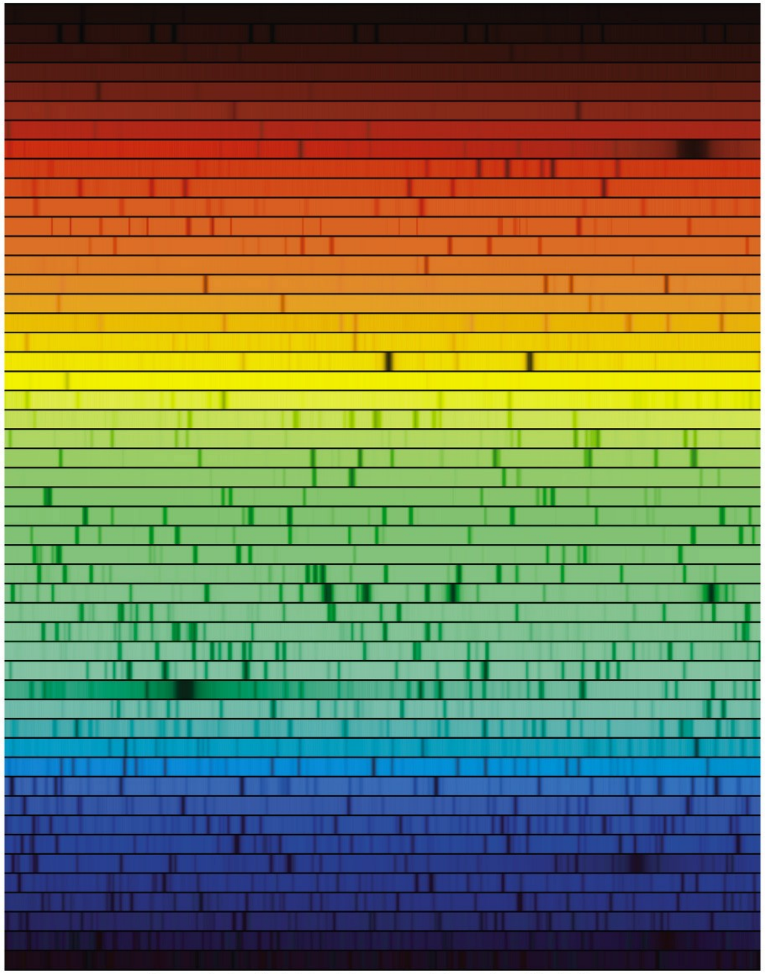
Chapter 4

Spectroscopy



Chapter 4 *Spectroscopy*

What's a spectrum?

Kirchoff's laws and the 3 types of spectra

The Formation of Spectral Lines

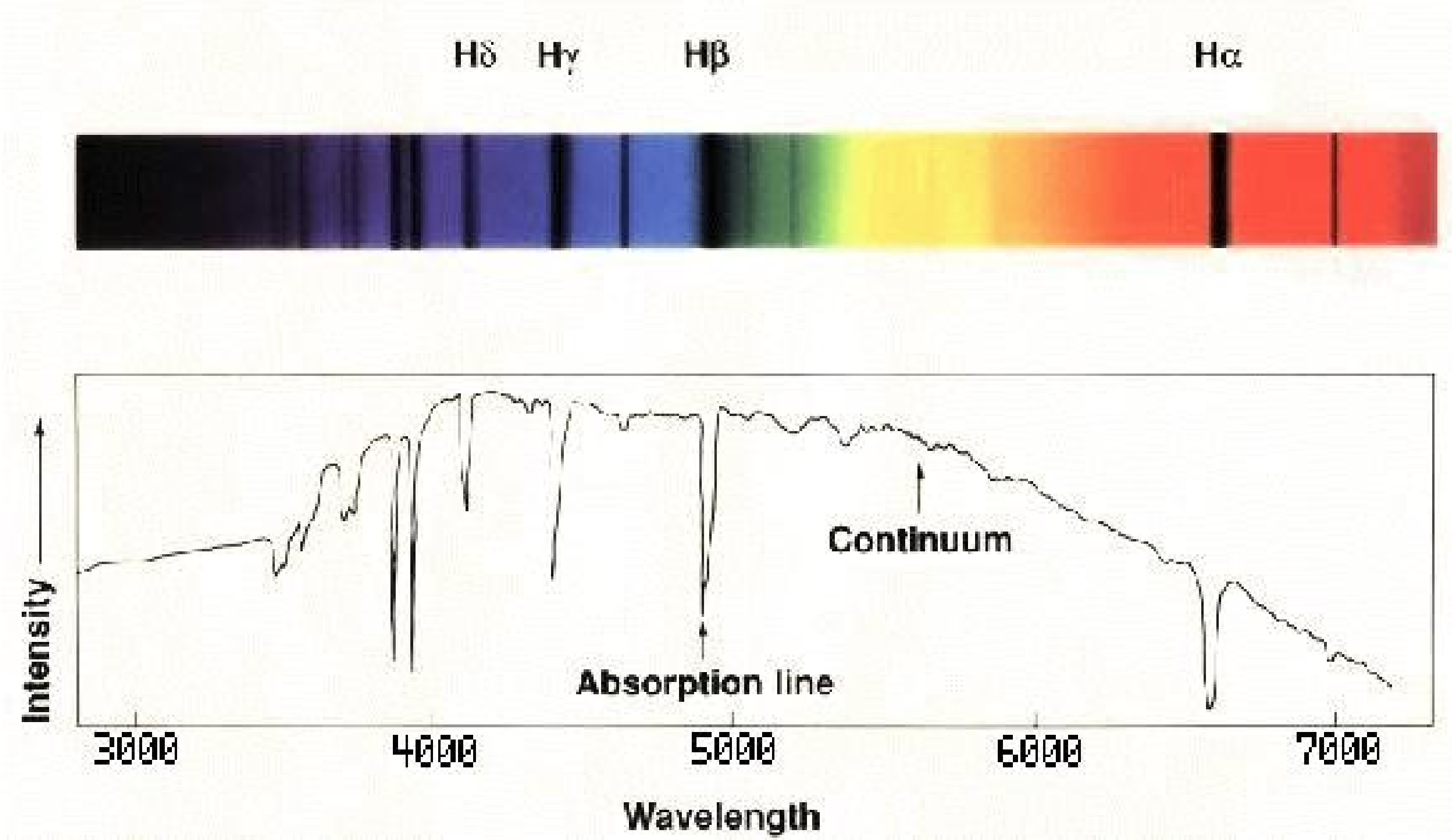
- **The Energy Levels of the Hydrogen Atom**
- **The Photoelectric Effect**

Molecules (skip)

What can we learn from spectra?

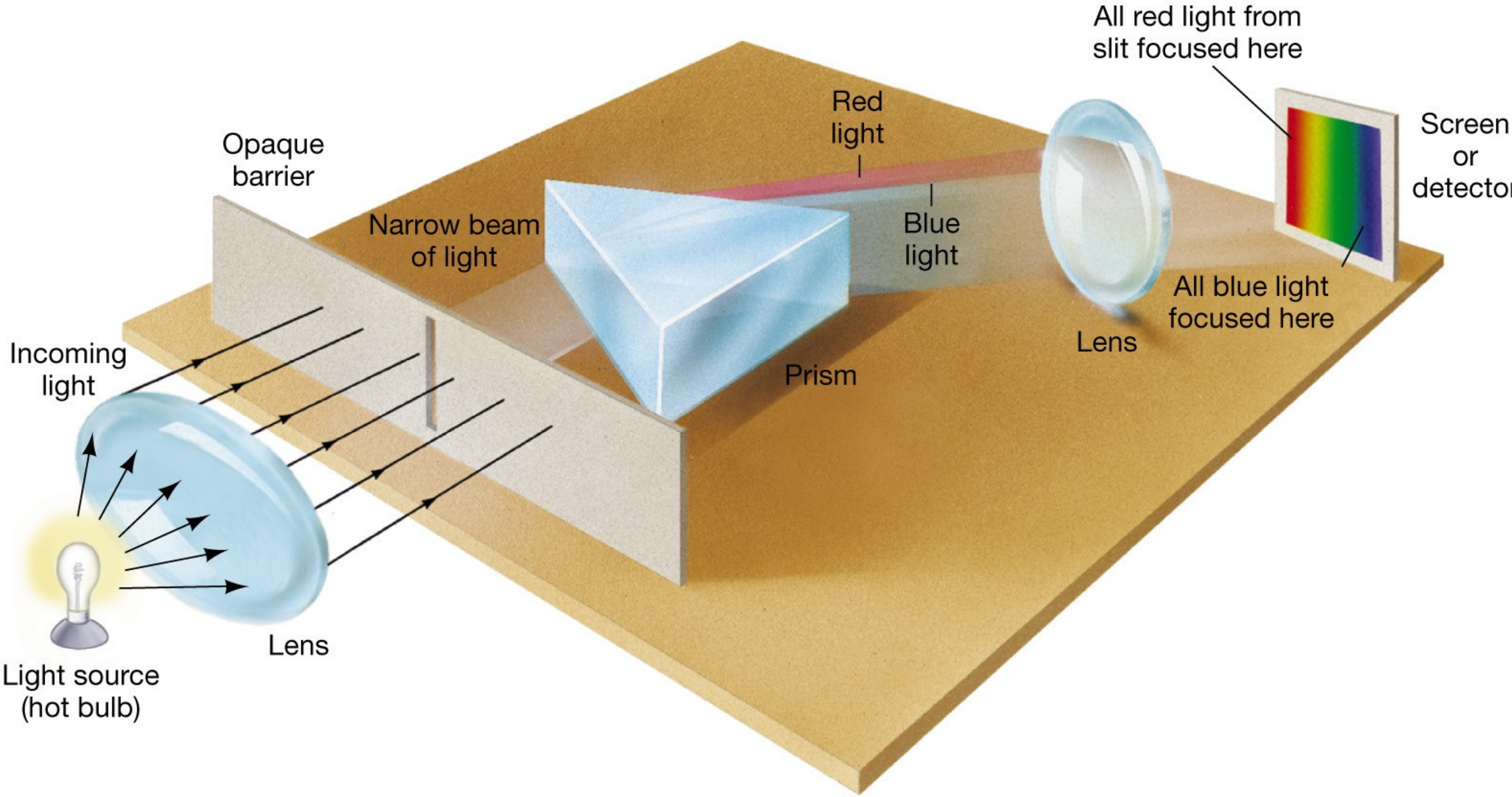
4.1 Spectral Lines

Spectrum: a graphic depiction of light intensity as a function of wavelength, frequency, or energy.



4.1 Spectral Lines

Spectroscope: splits light into component colors



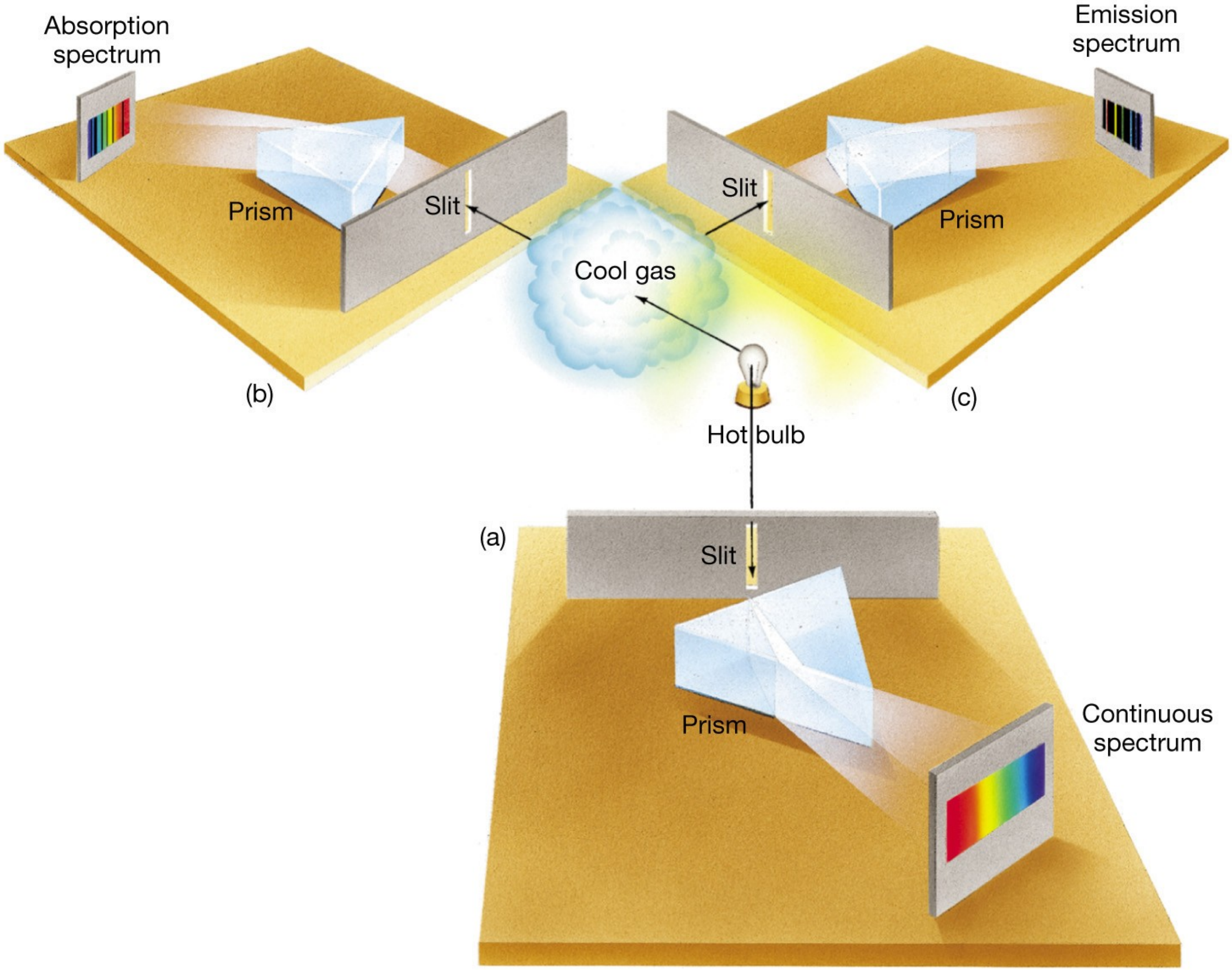
4.1 Spectral Lines

Kirchhoff's laws:

- **Luminous solid, liquid, or dense gas produces <u>continuous spectrum</u>**
- **Low-density, hot gas produces <u>emission spectrum</u>**
- **Continuous spectrum incident on cool, thin gas produces <u>absorption spectrum</u>**

4.1 Spectral Lines

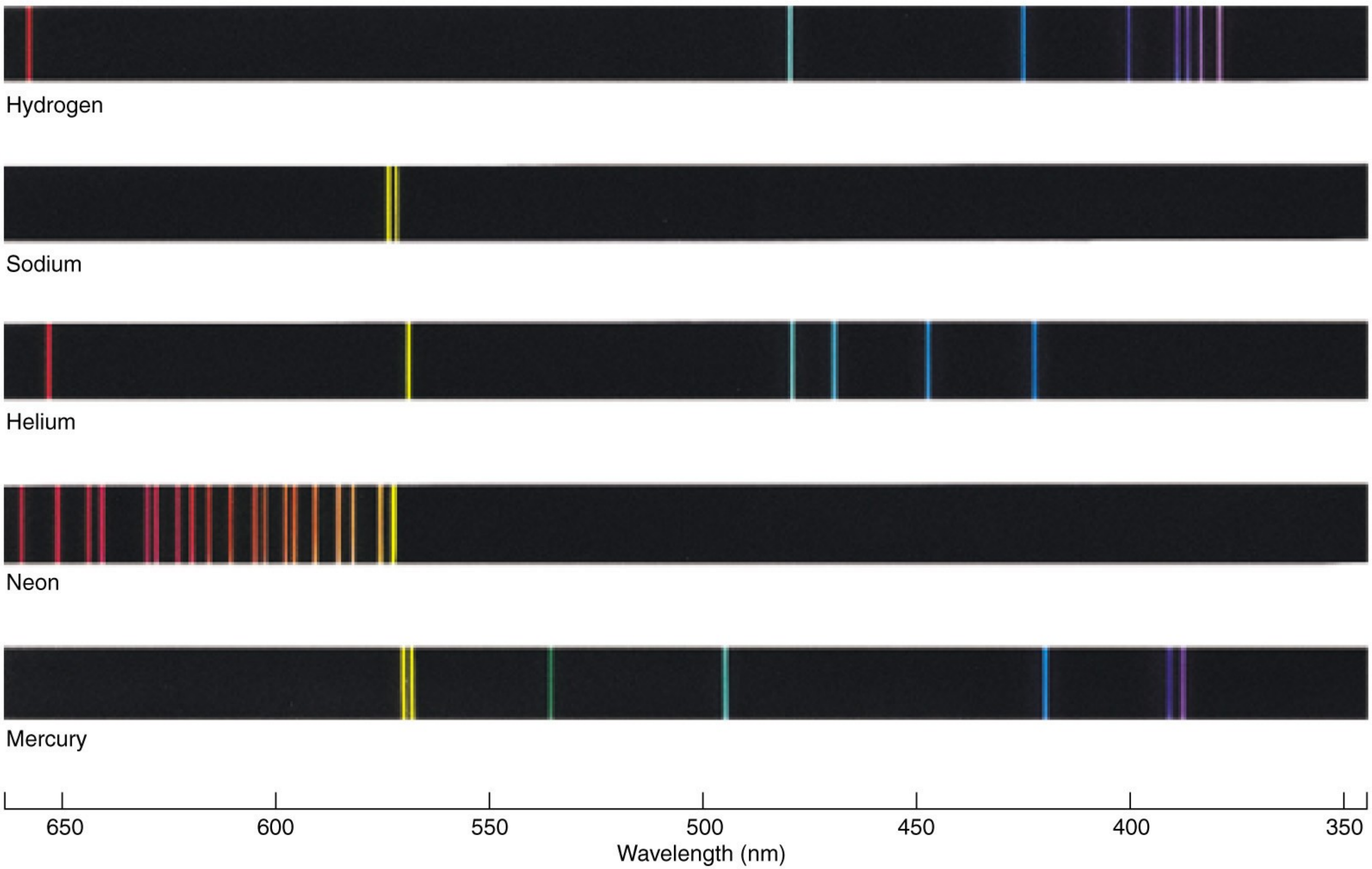
Kirchhoff's laws illustrated:



4.1 Spectral Lines

Emission line spectra **each element has a characteristic spectrum.**

Demo: Ne, Hydrogen, ?



4.2 The Formation of Spectral Lines

Explaining spectral lines required a new model of the atom.

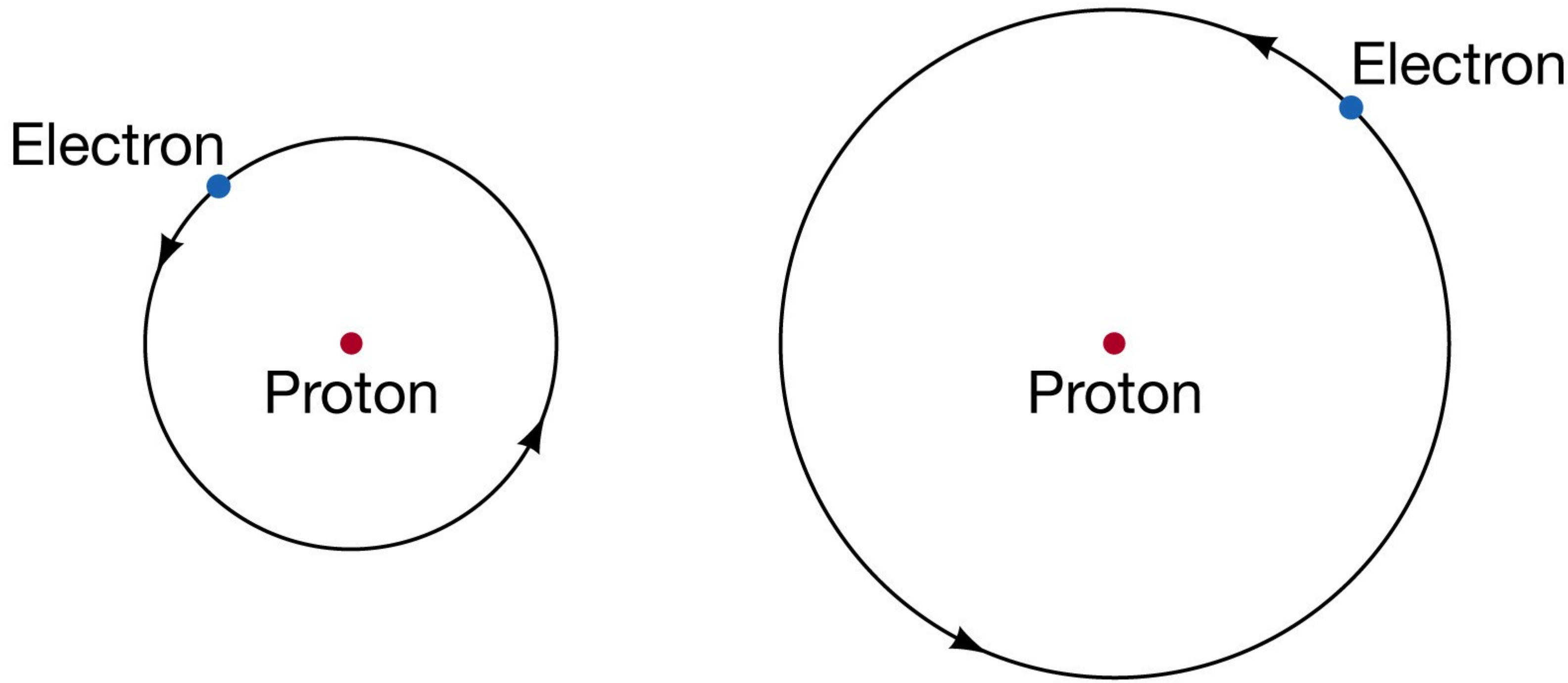
Bohr's model of H was the first to explain the H spectrum. He built upon this knowledge:

1) Atoms are the building blocks of elements.
2) Atoms are made up of charged particles.
-- J.J. Thompson had isolated the electron.
3) Accelerating electrons emit E-M radiation.
4) Einstein: light comes in photons
5) Planck said $E_{photon} = hf$. ($h = 6.63 \times 10^{-34}$ kg m^2/s)
6) Balmer found equation for the H emission lines:

$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right); n = 3, 4, \ldots$$

4.2 The Formation of Spectral Lines

Bohr model of H had certain allowed "orbits" for electron:

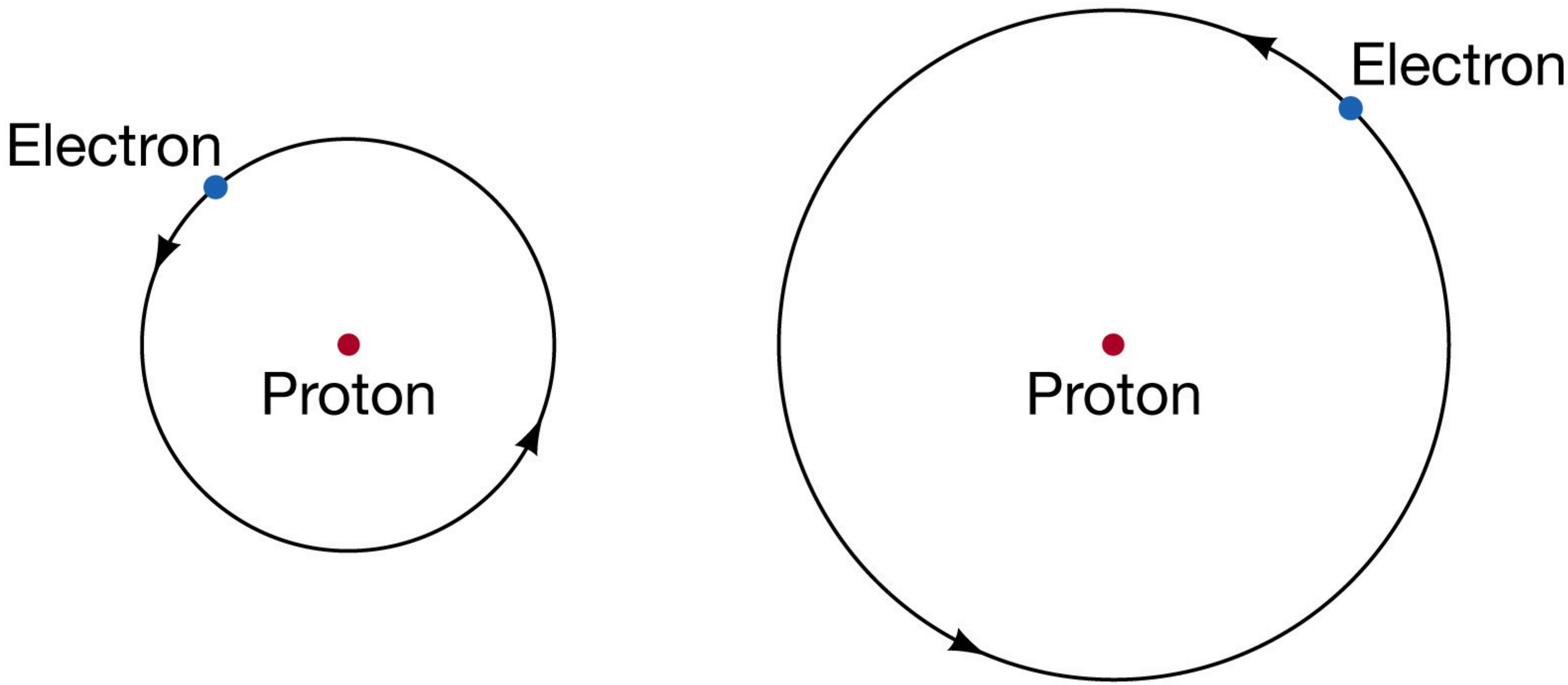


(a) Ground state n=1 (b) Excited states n=2,3,4,...

4.2 The Formation of Spectral Lines

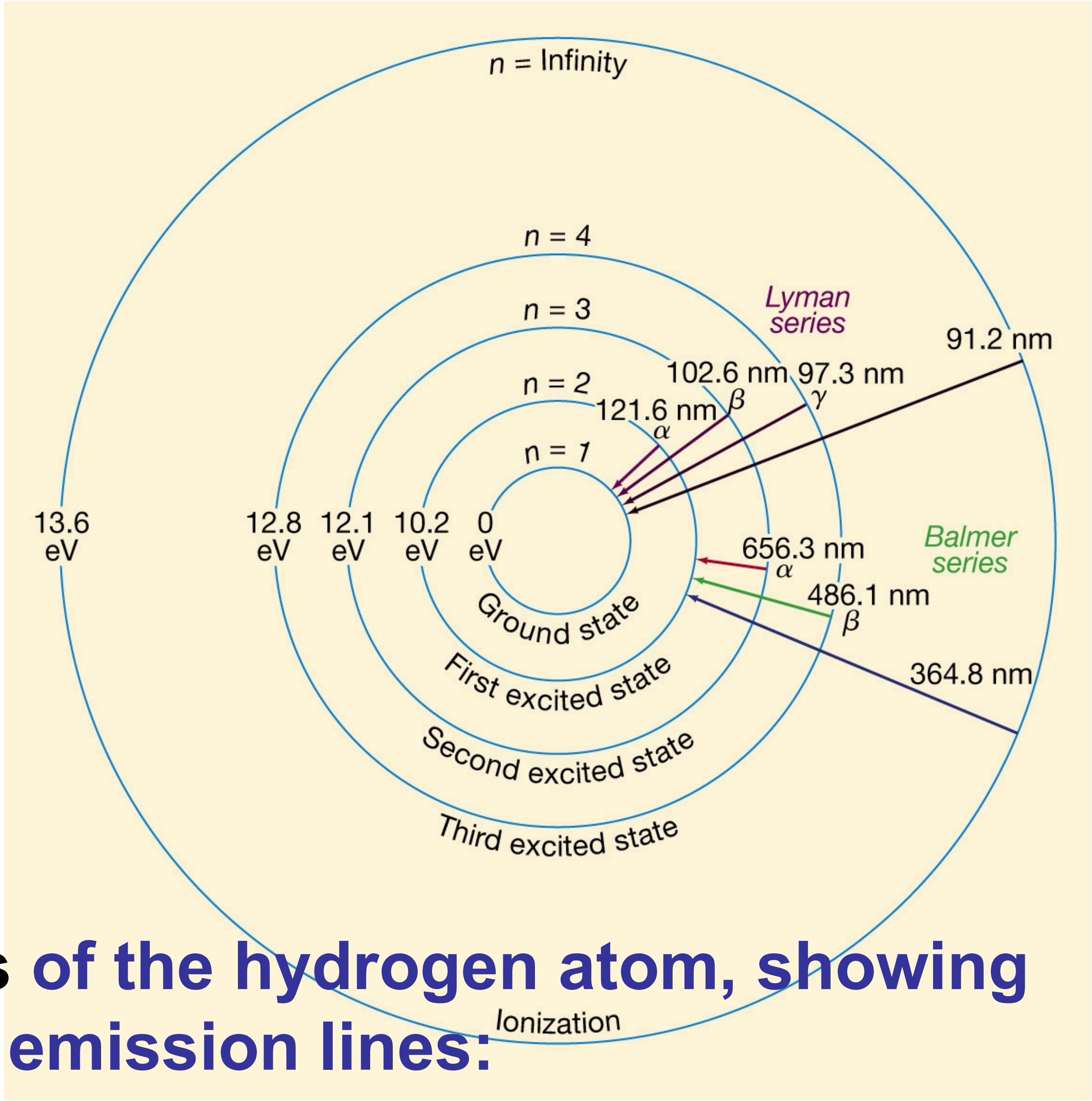
Emission photon energies **correspond to energy differences between allowed levels.**

$$E_{photon} = \Delta E_{atomic\ levels}$$



(a) Ground state (b) Excited state

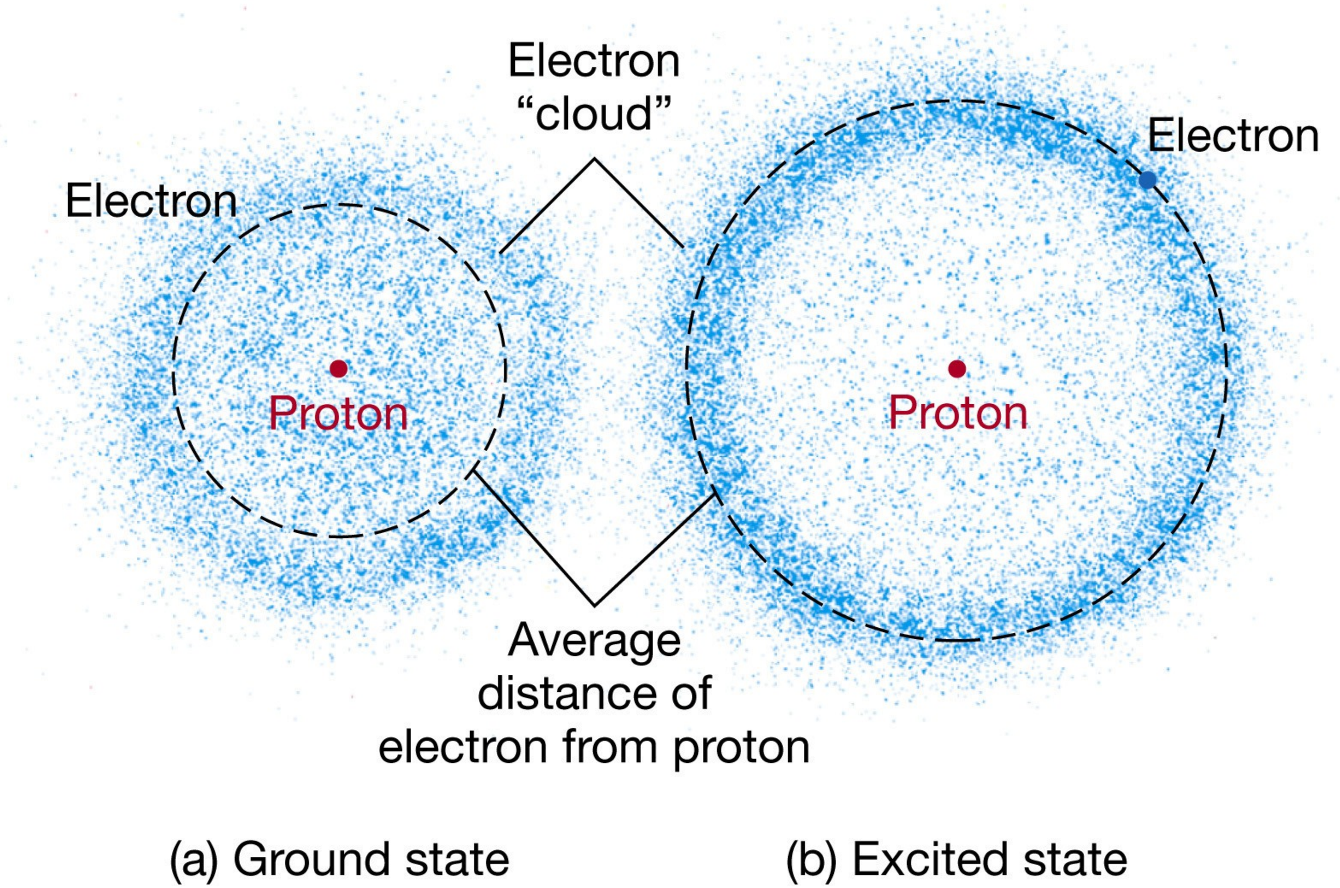
4.2 The Formation of Spectral Lines



Energy levels of the hydrogen atom, showing two series of emission lines:

4.2 The Formation of Spectral Lines

Modern model has electron "cloud" rather than orbit:



Light as a particle

Light particles (photons) each have energy *E*:

$$E = hf$$

Here, *h* is Planck's constant:

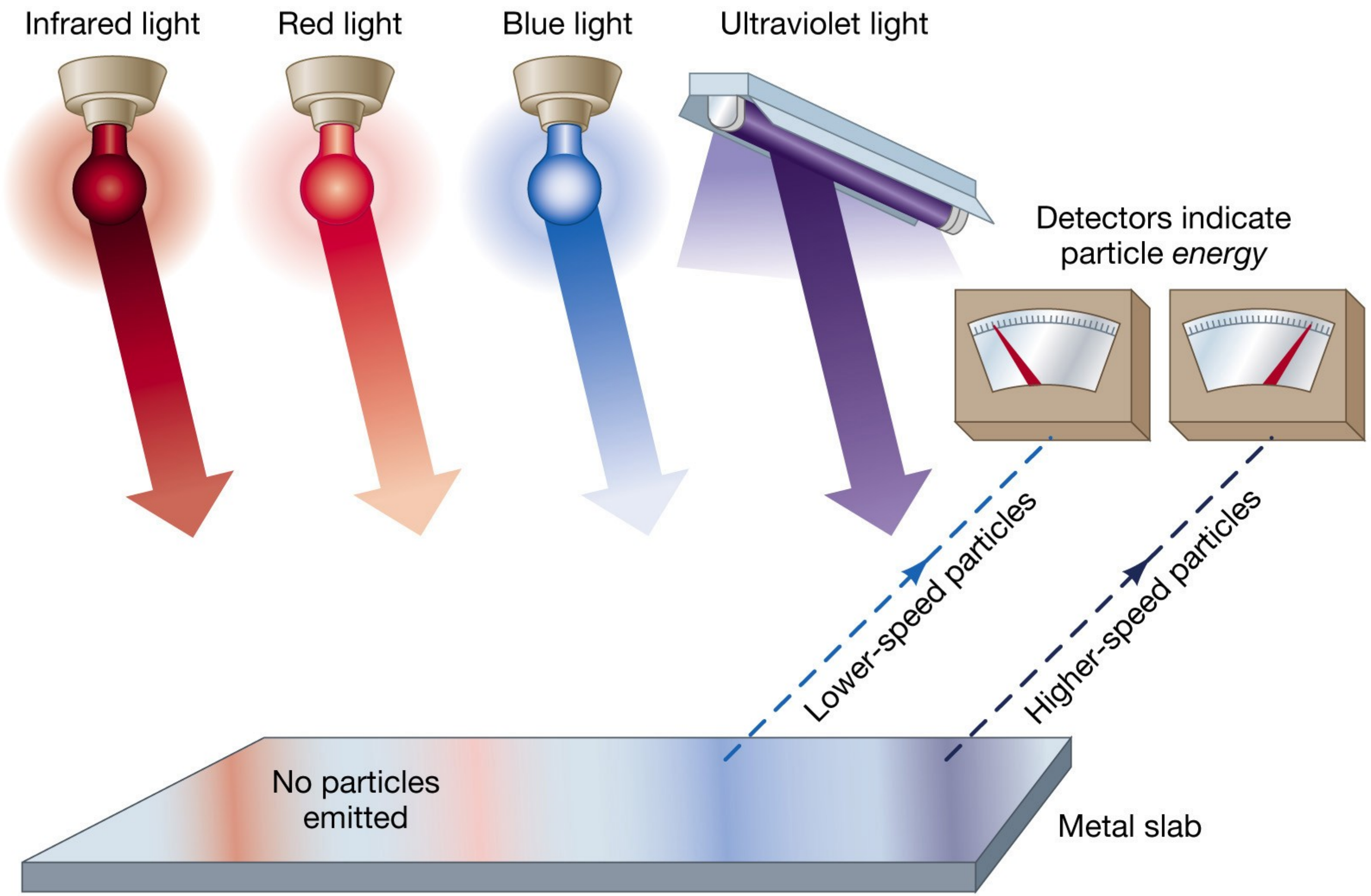
$$h = 6.63 \times 10^{-34}\,\mathrm{J \cdot s}$$

Photon *Energy* can also be related to wavelength, e.g.

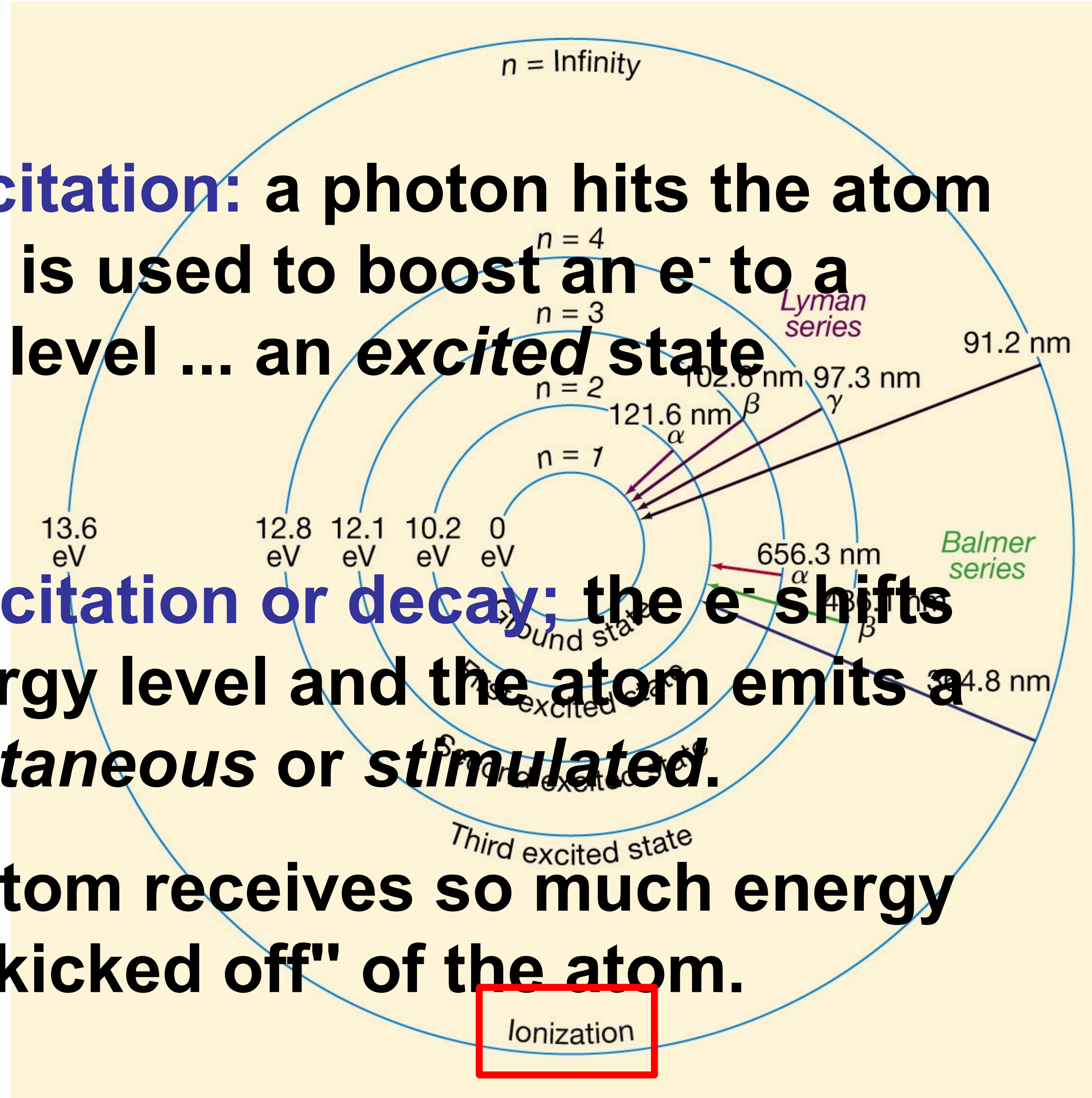
$E=hc/\lambda = 1240\ eV/\lambda$ (nm)

Light as a particle

Photoelectric effect can be understood only if light behaves like particles



4.2 The Formation of Spectral Lines

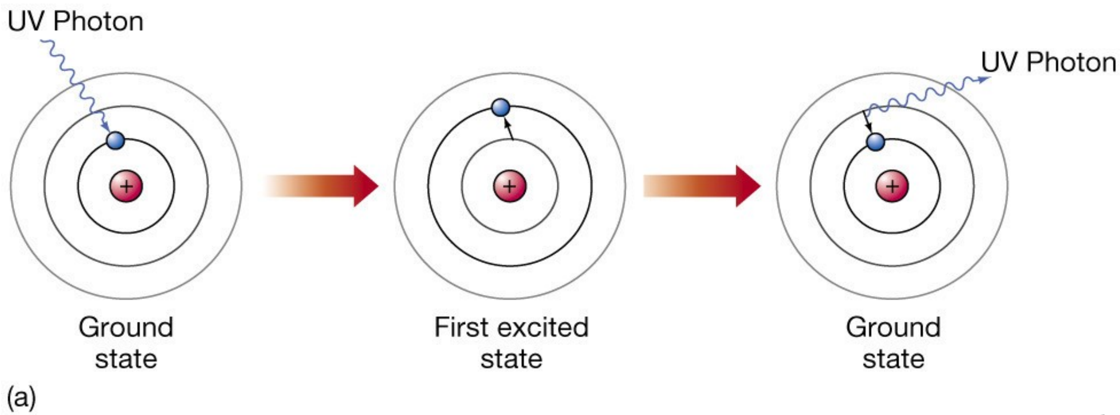


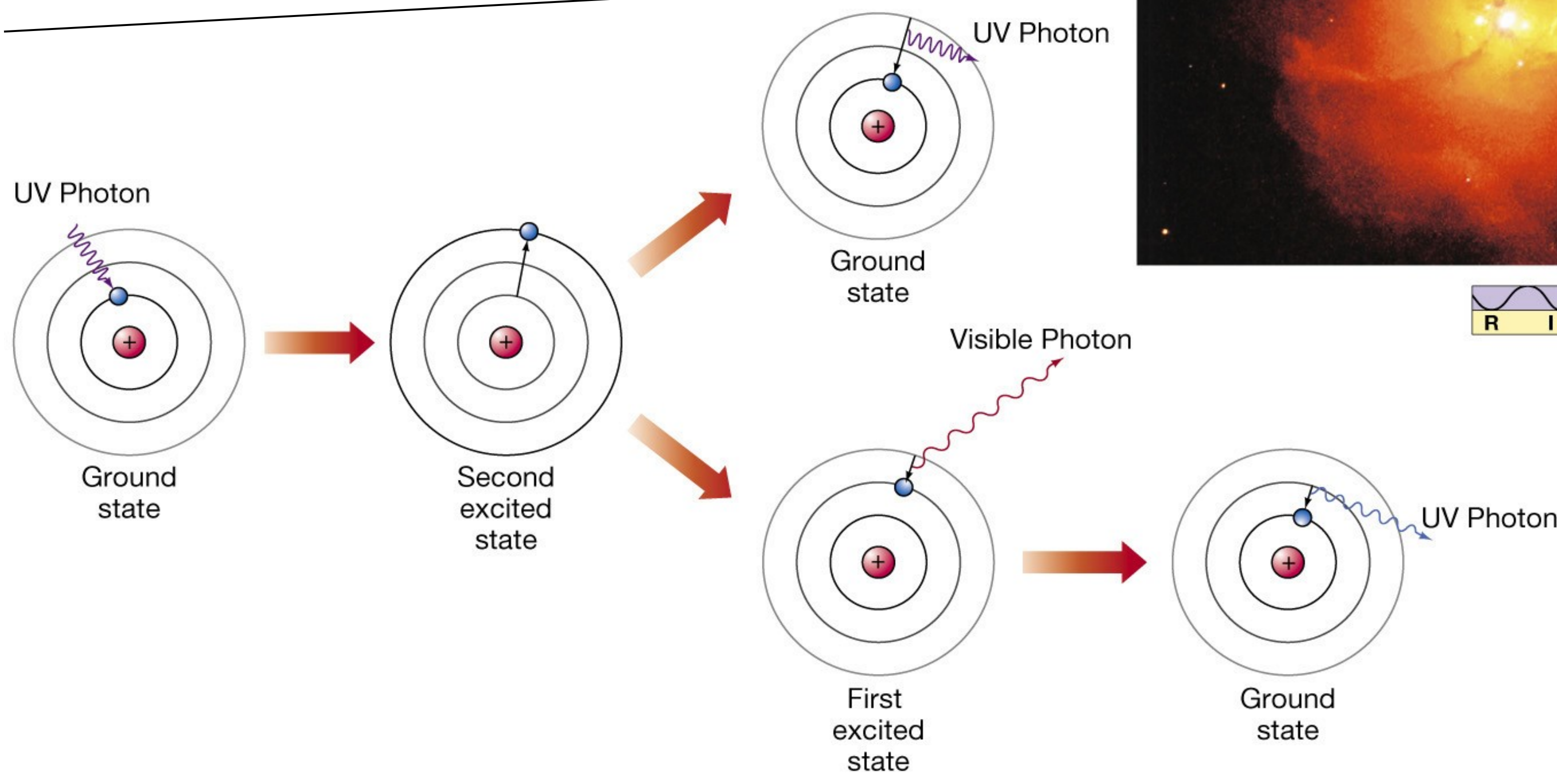
Absorption - excitation: **a photon hits the atom and its energy is used to boost an e$^-$ to a higher energy level ... an *excited* state**

Emission - deexcitation or decay; **the e$^-$ shifts to a lower energy level and the atom emits a photon. *Spontaneous* or *stimulated*.**

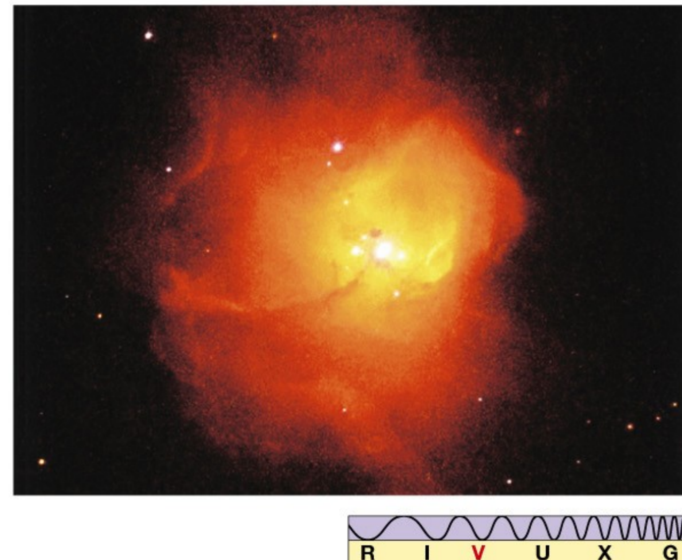
Ionization: the atom receives so much energy that the e- is "kicked off" of the atom.

4.2 The Formation of Spectral Lines





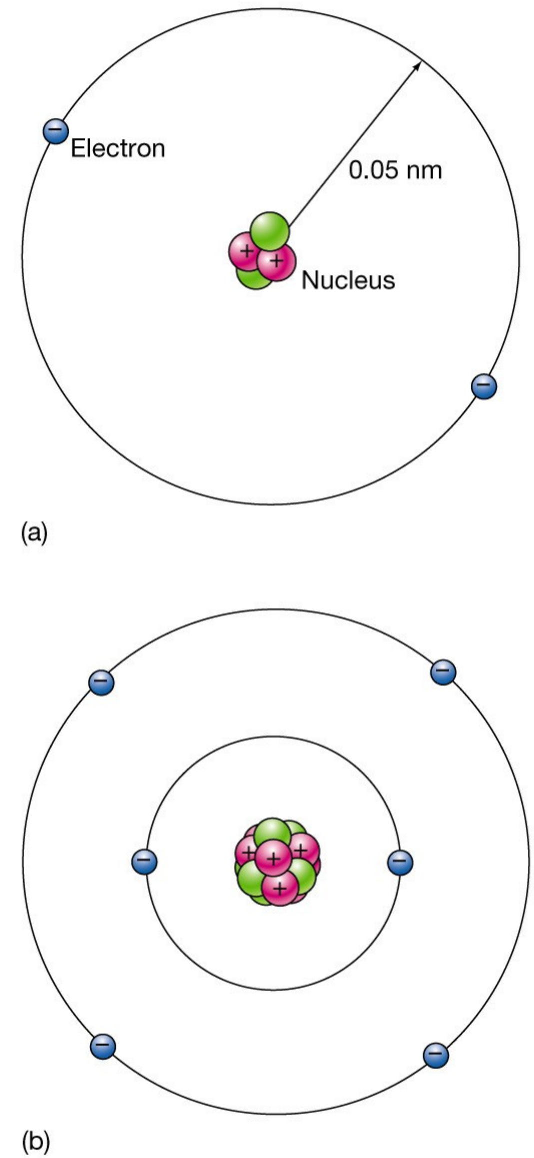
2 Ways to decay.



4.2 The Formation of Spectral Lines

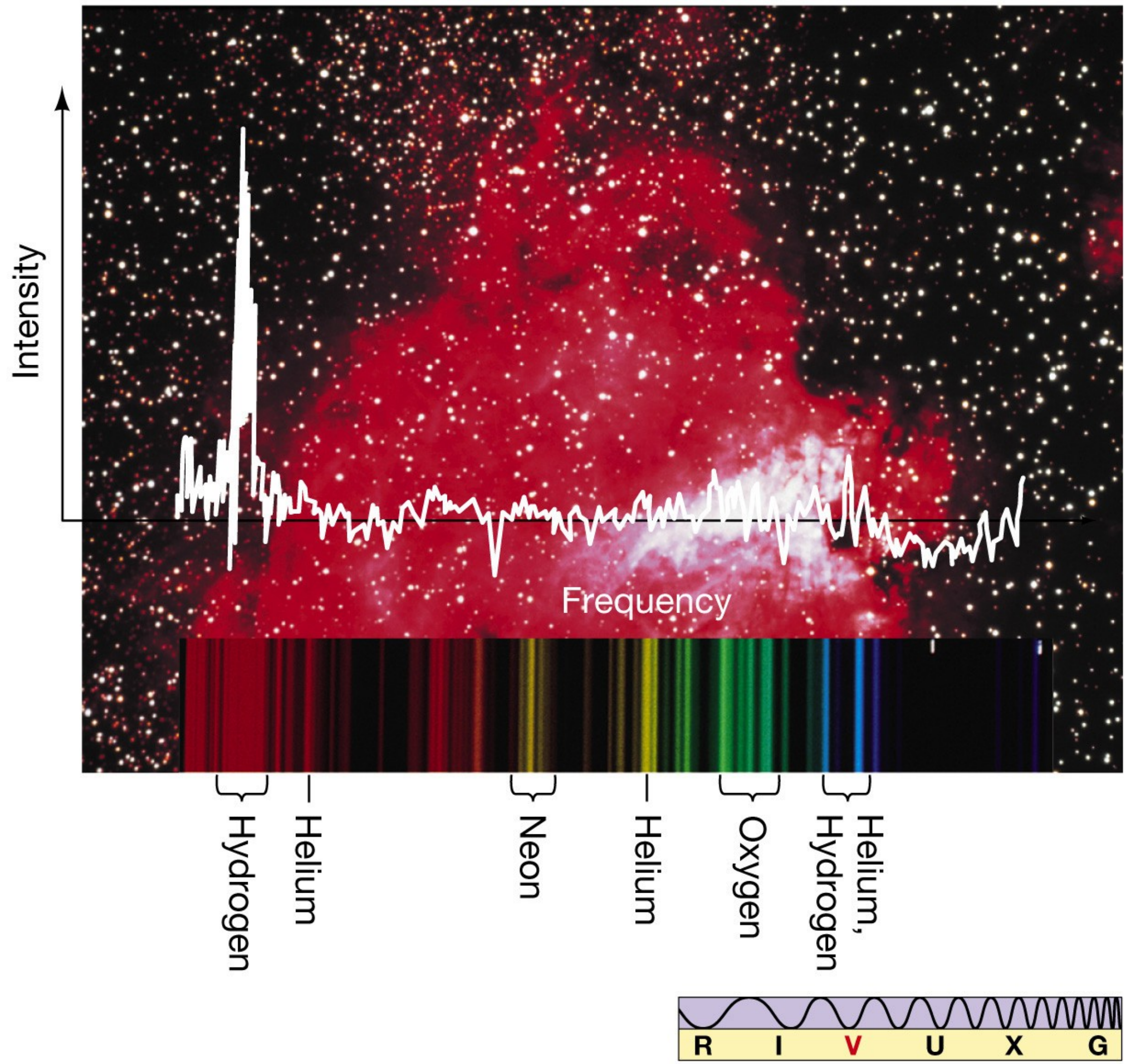
Multielectron atoms: much more complicated spectra, many more possible states

Ionization changes energy levels



4.2 The Formation of Spectral Lines

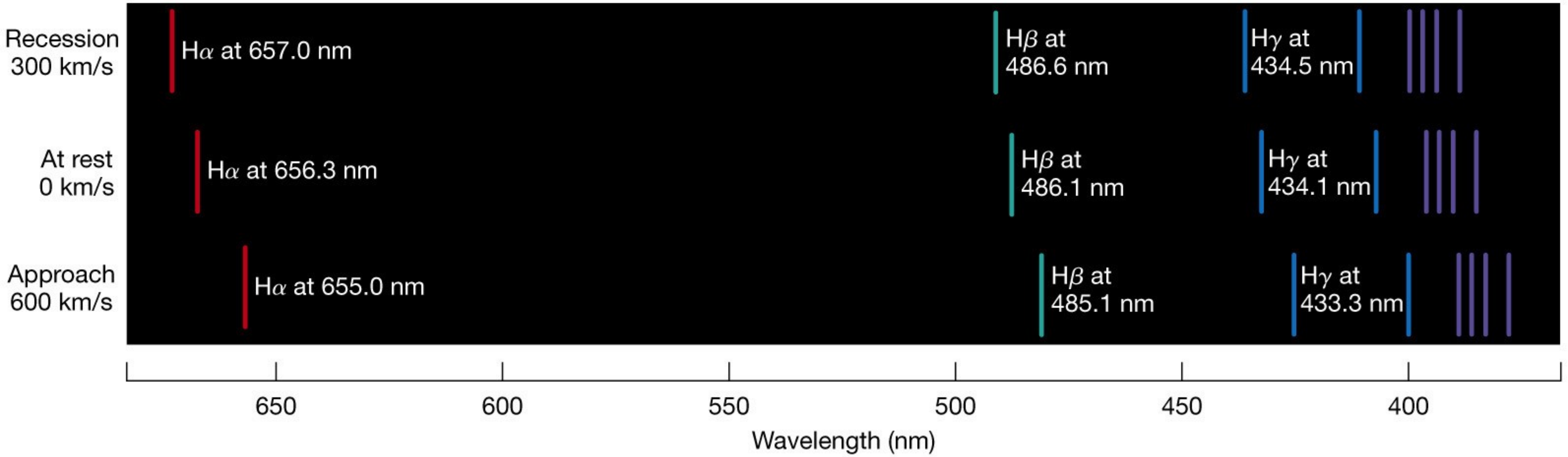
Emission lines can be used to identify atoms:



4.4 Spectral-Line Analysis

Information from spectral lines:

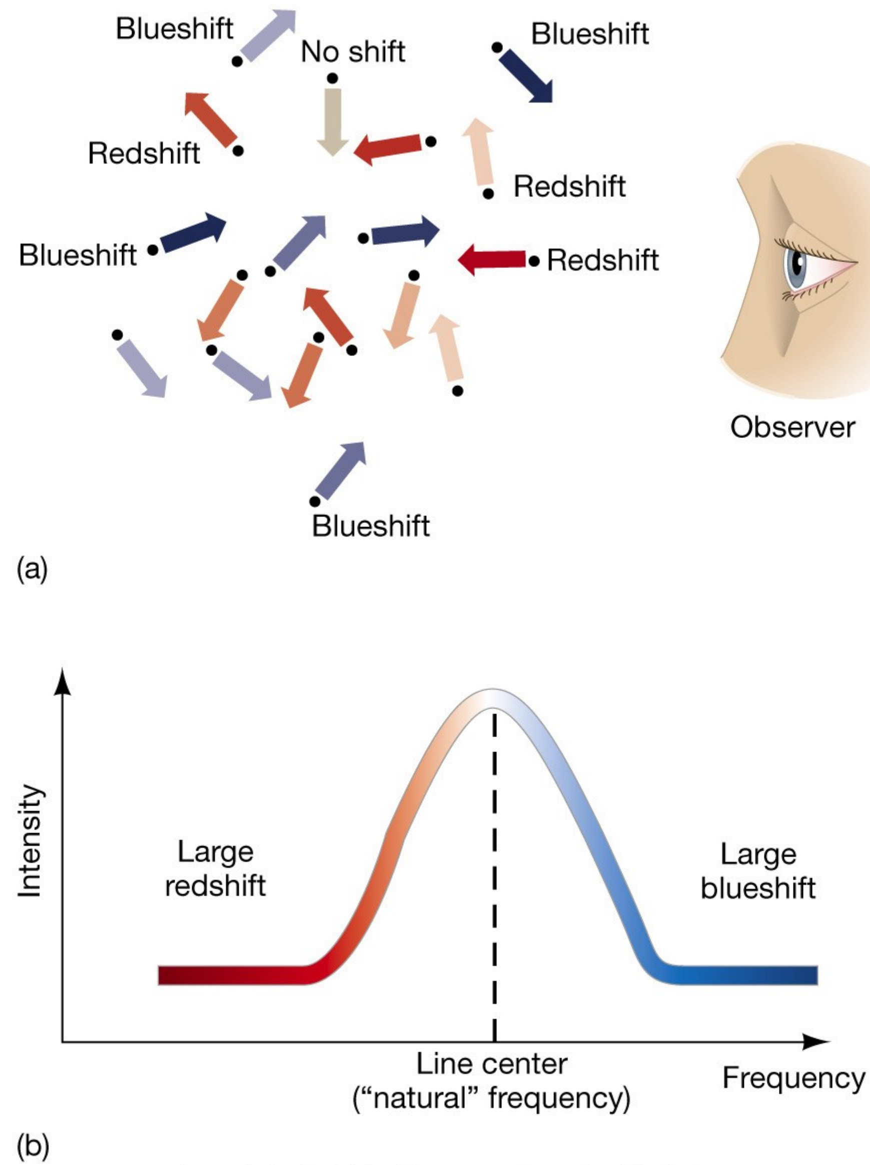
- **Chemical composition – from line strength, presence of lines**
- **Temperature – from line strengths, presence of lines**
- **Radial velocity - doppler shifting of all lines**



4.4 Spectral-Line Analysis

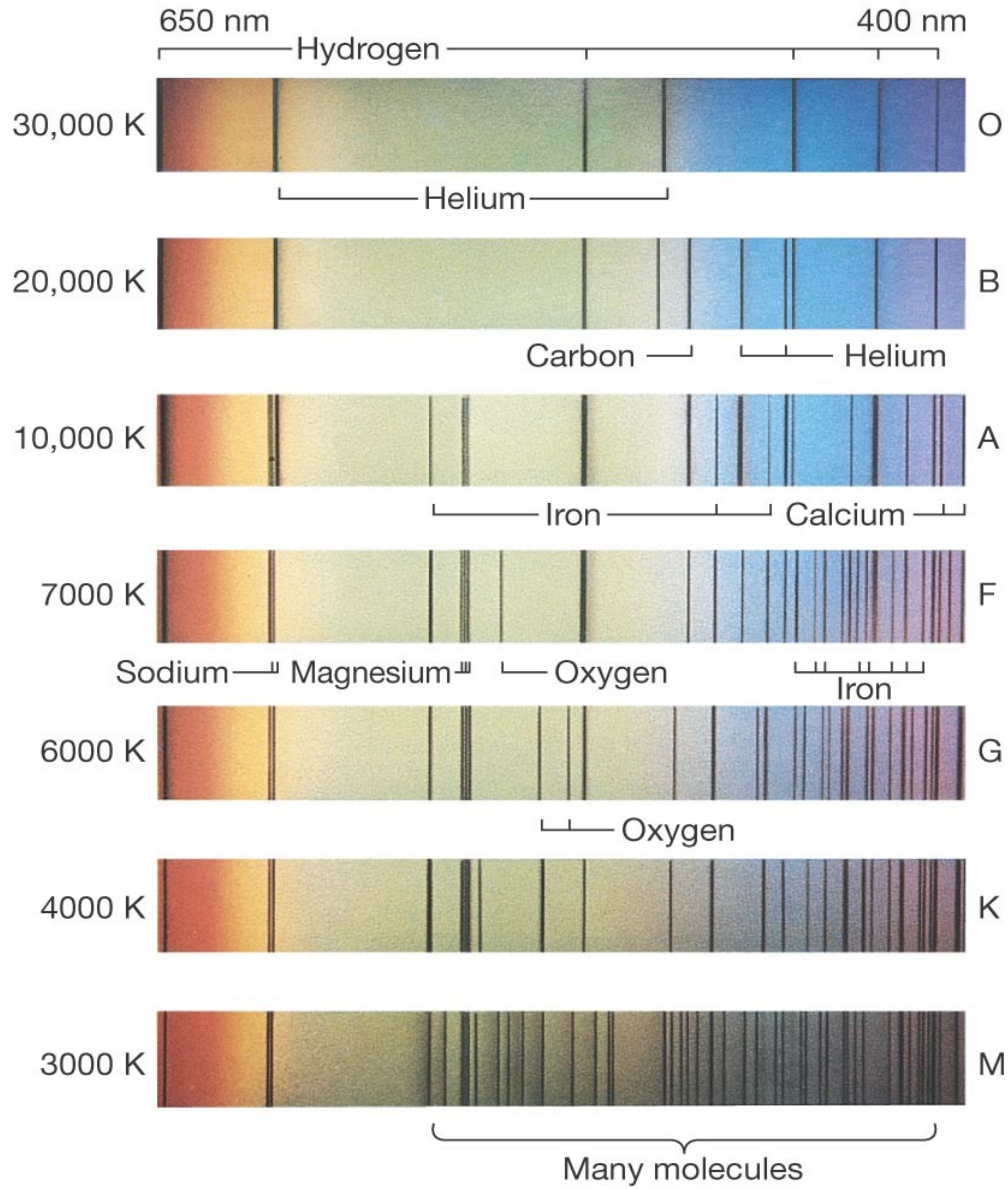
Line broadening can be due to Doppler shifting

- from thermal motion
- from rotation

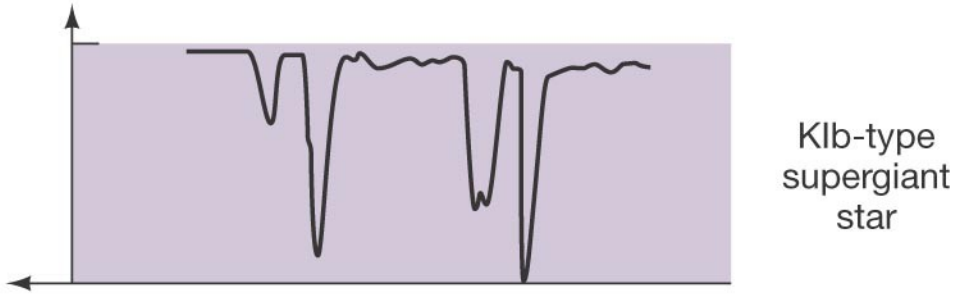


4.4 Spectral-Line Analysis

Spectral Types - based on the presence of lines.

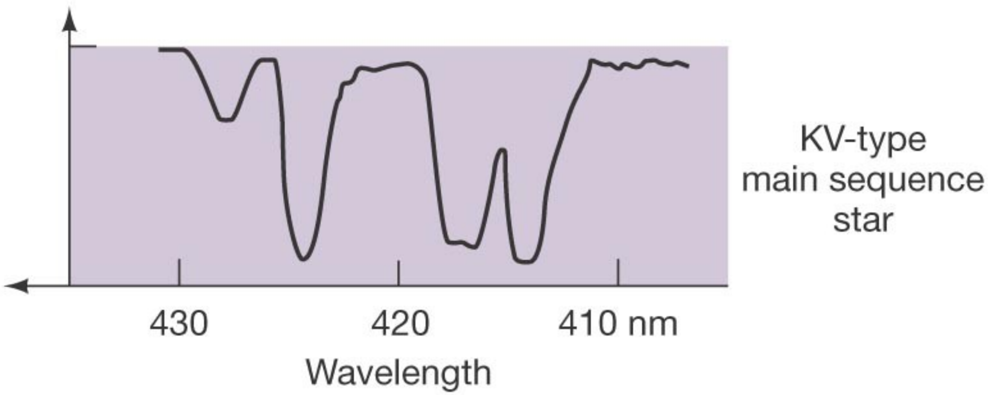


4.4 Spectral-Line Analysis



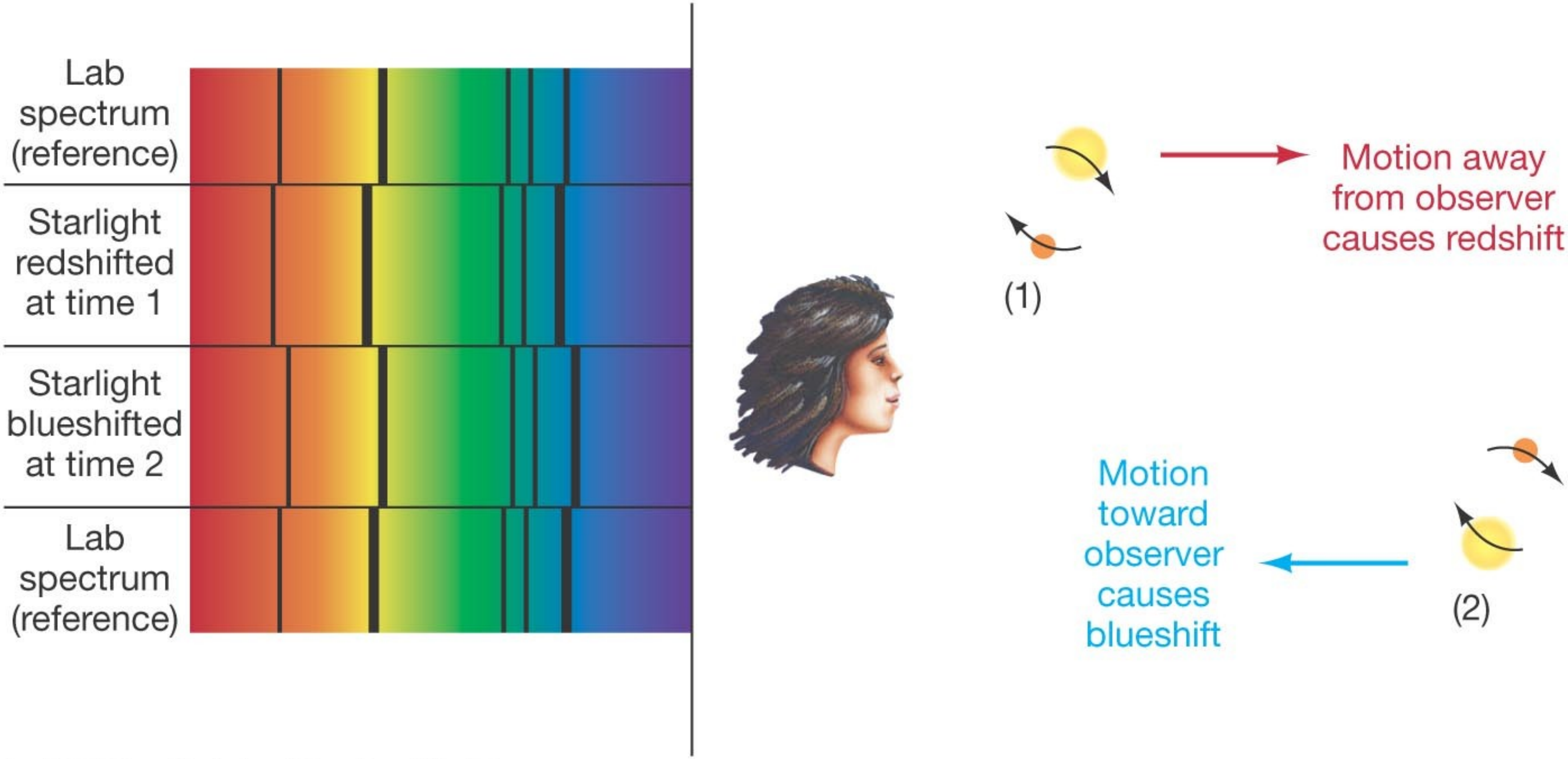
(b)

Line broadening caused by higher gas pressure on the surface of the star.



(c)

4.4 Spectral-Line Analysis



4.4 Spectral-Line Analysis

TABLE 4.1 Spectral Information Derived from Starlight

Observed Spectral Characteristic	Information Provided
Peak frequency or wavelength (continuous spectra only)	Temperature (Wien's law)
Lines present	Composition, temperature
Line intensities	Composition, temperature
Line width	Temperature, turbulence, rotation speed, density, magnetic field
Doppler shift	Line-of-sight velocity

Summary of Chapter 4

• Spectroscope splits light beam into component frequencies

• Kirchoff's laws describe how the 3 types of spectra can form.

•Continuous, emission, and absorption spectra

• Both emission and absorption spectra can be observed from one gas cloud depending on line-of-sight.

Summary of Chapter 4, cont.

- Spectra can be explained using atomic models, with electrons occupying specific orbitals/energy levels.

- Emission and absorption lines result from transitions between orbitals.

- Spectra can give us information about a stars temperature, composition, rotation, radial velocity, magnetic field strength, surface gravity (pressure) → star size.