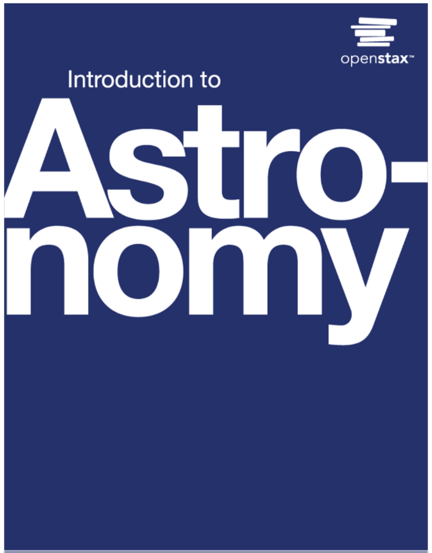
ASTRONOMY

Chapter 5 RADIATION AND SPECTRA



openstax™

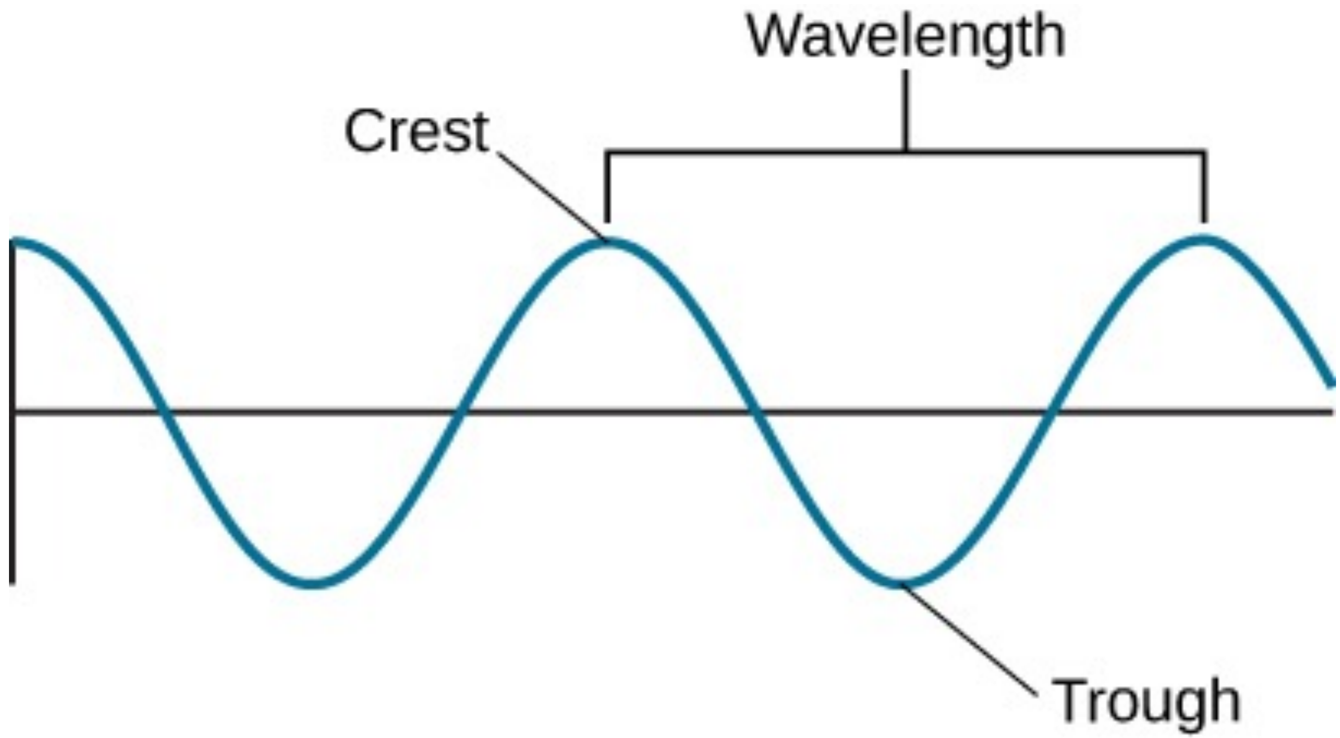
FIGURE 5.2

James Clerk Maxwell (1831–1879). Maxwell unified the rules governing electricity and magnetism into a coherent theory.

FIGURE 5.3

Making Waves. An oscillation in a pool of water creates an expanding disturbance called a wave. (credit: modification of work by "vastateparksstaff"/Flickr)

FIGURE 5.4



Characterizing Waves. Electromagnetic ***radiation*** has wave-like characteristics. The wavelength (λ) is the distance between crests, the frequency (f) is the number of cycles per second, and the speed (c) is the distance the wave covers during a specified period of time (e.g., kilometers per second).

EM Waves

vs.

Radiation

vs.

“Radiation”

THE ELECTROMAGNETIC SPECTRUM

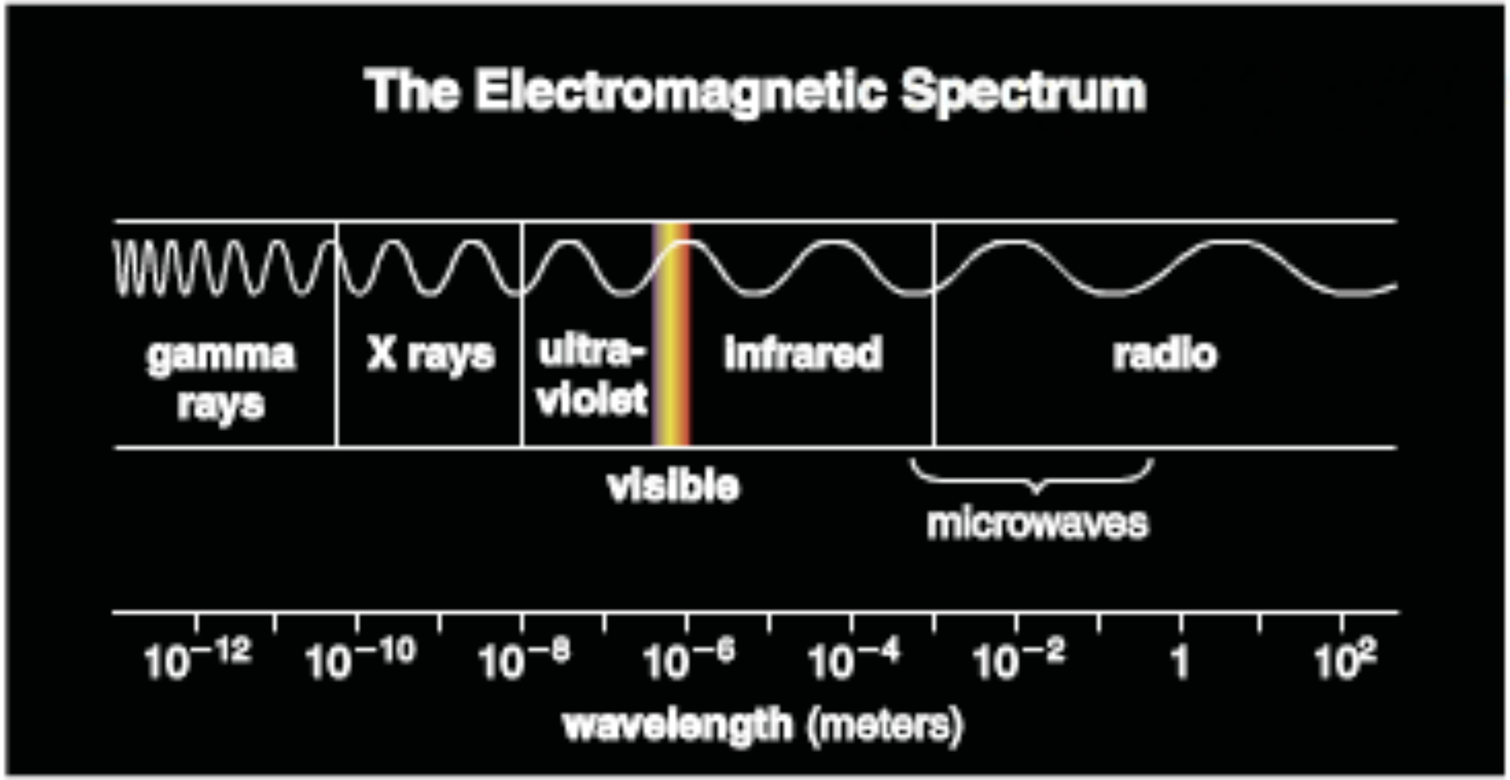
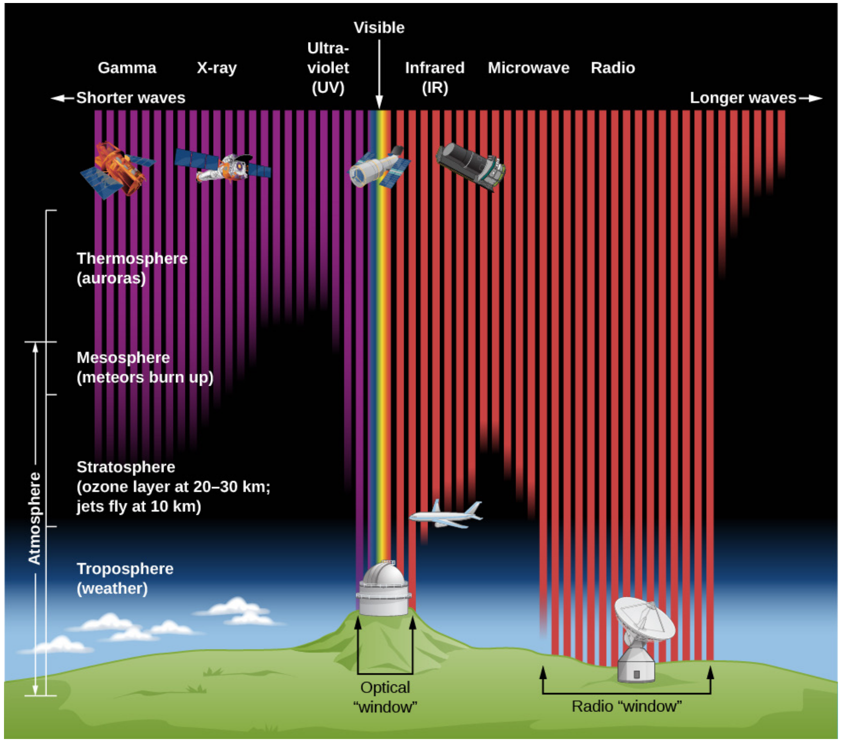


Figure 2 | The electromagnetic spectrum.

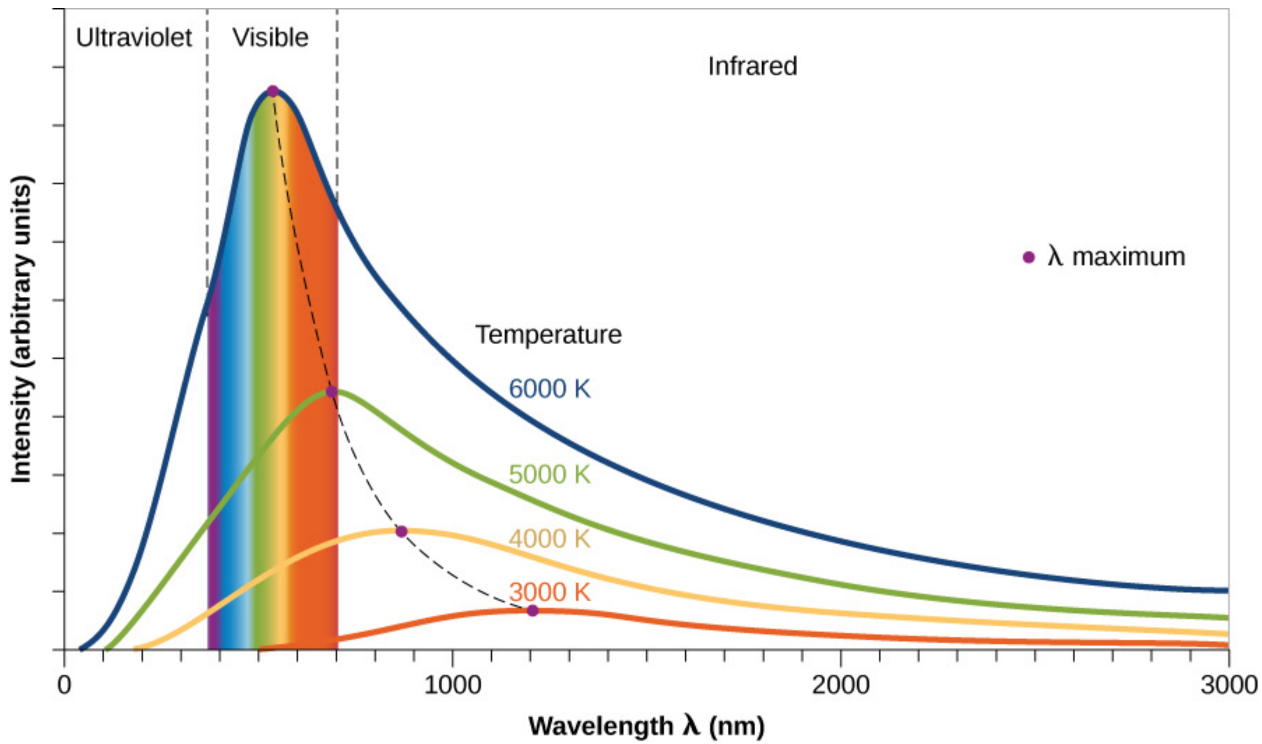
Figure 2. Page 80. *The Cosmic Perspective Fundamentals*. Publisher: Addison-Wesley. © 2010

FIGURE 5.6



Radiation and Earth's Atmosphere. This figure shows the bands of the electromagnetic spectrum and how well Earth's atmosphere transmits them. Note that high-frequency waves from space do not make it to the surface and must therefore be observed from space. Some infrared and microwaves are absorbed by water and thus are best observed from high altitudes. Low-frequency radio waves are blocked by Earth's ionosphere. (credit: modification of work by STScI/JHU/NASA)

FIGURE 5.8



Radiation Laws Illustrated. This graph shows in arbitrary units how many photons are given off at each wavelength for objects at four different temperatures. The wavelengths corresponding to visible light are shown by the colored bands. Note that at hotter temperatures, more energy (in the form of photons) is emitted at all wavelengths. The higher the temperature, the shorter the wavelength at which the peak amount of energy is radiated (this is known as Wien's law).

PLANCK'S CONSTANT & THE ENERGY OF A PHOTON

In 1900, Max Planck found a formula that fit the experimental data for thermal (blackbody) radiation

To do this he needed to assume that the energy emitted was **quantized,**

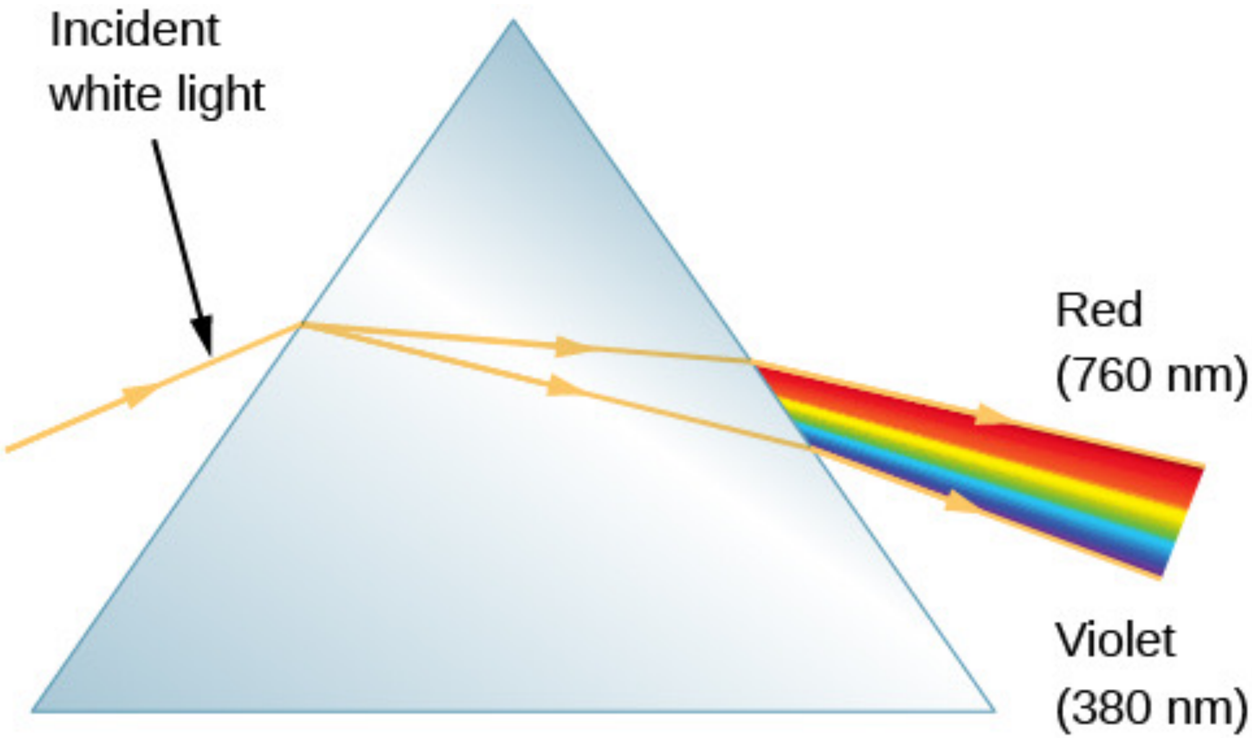
- that is, that it came in small “chunks” proportional to the frequency of vibration

Energy = Planck's constant x Frequency

SPECTRA

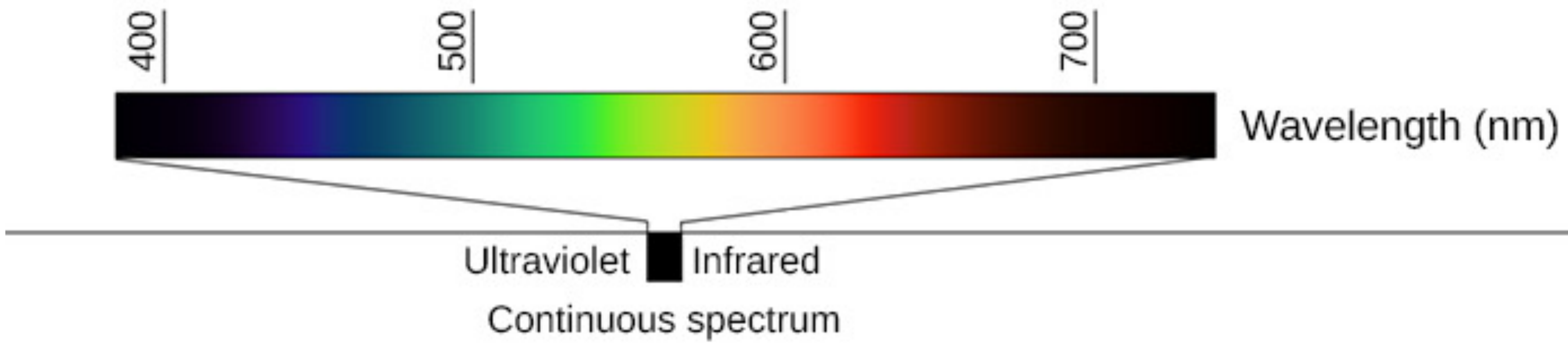
http://www.biographyonline.net/scientists/isaac-newton.html

FIGURE 5.9



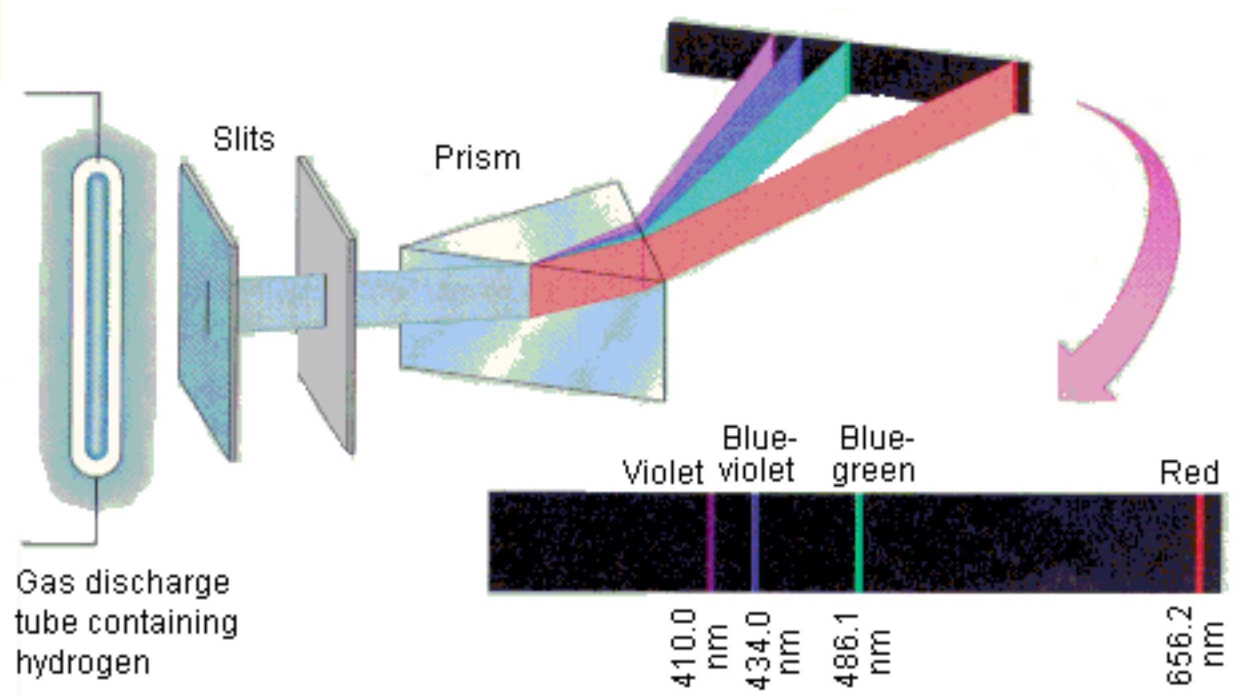
Action of a Prism. When we pass a beam of white sunlight through a prism, we see a rainbow-colored band of light that we call a continuous spectrum.

FIGURE 5.10



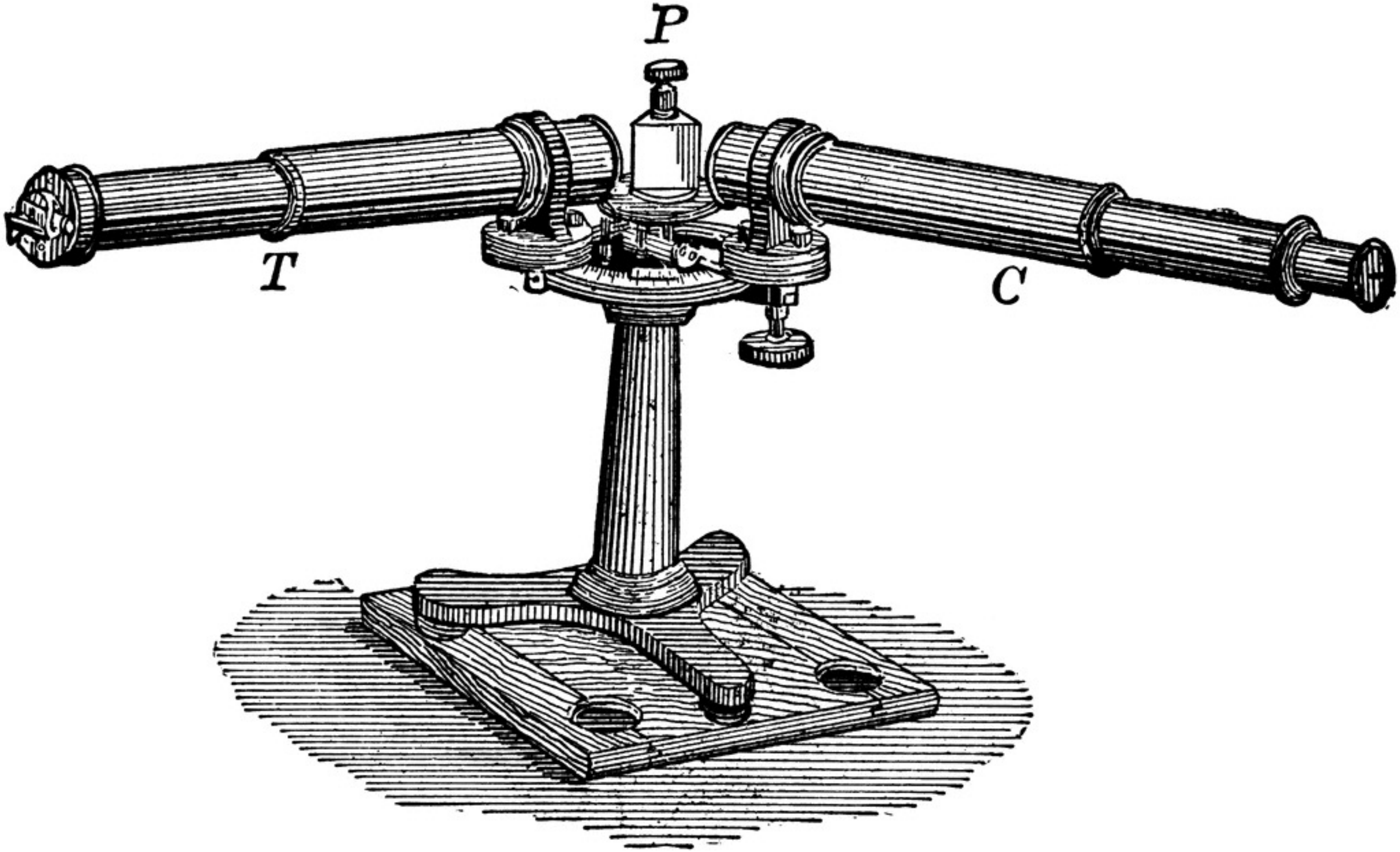
Continuous Spectrum. When white light passes through a prism, it is dispersed and forms a continuous spectrum of all the colors. Although it is hard to see in this printed version, in a well-dispersed spectrum, many subtle gradations in color are visible as your eye scans from one end (violet) to the other (red).

ATOMIC SPECTRA



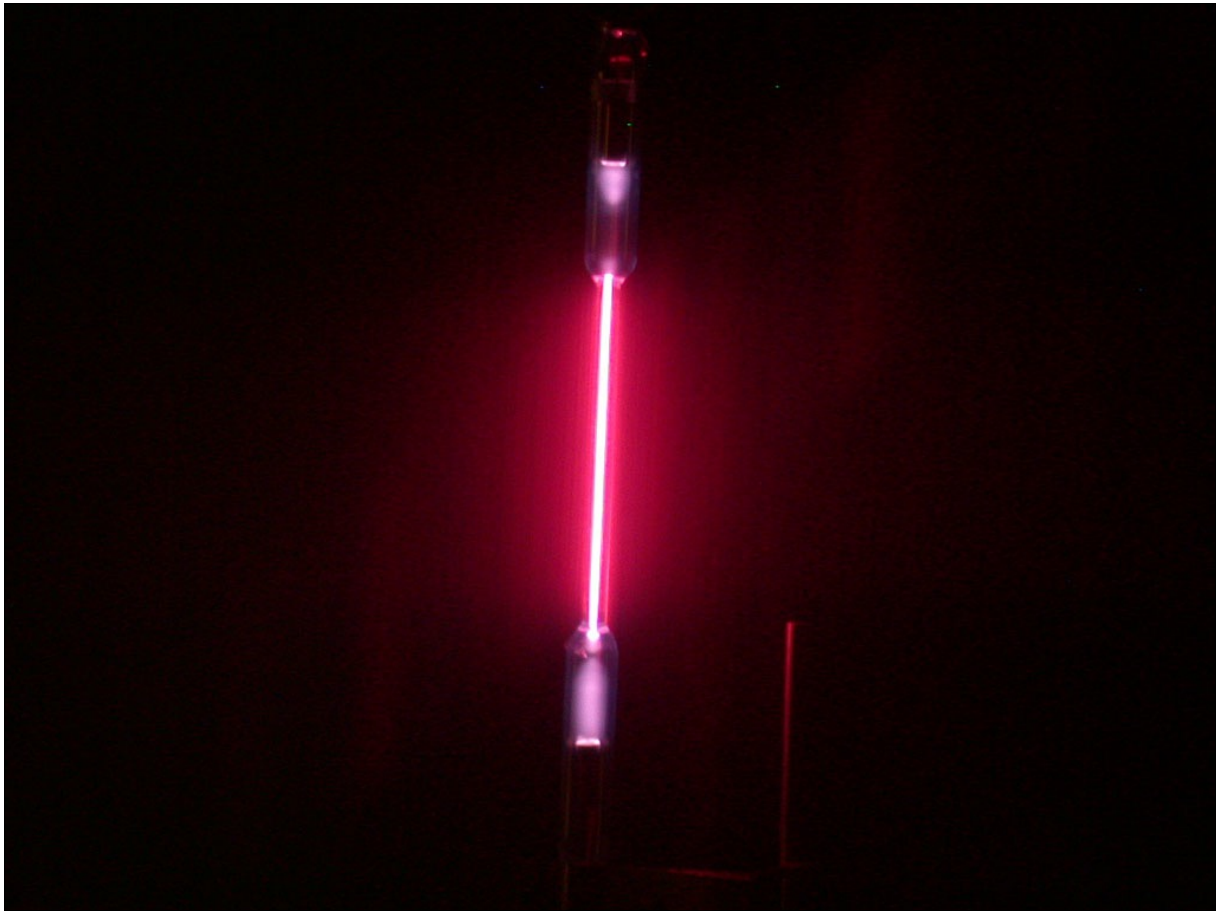
http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch6/bohr.php

A SPECTROSCOPE



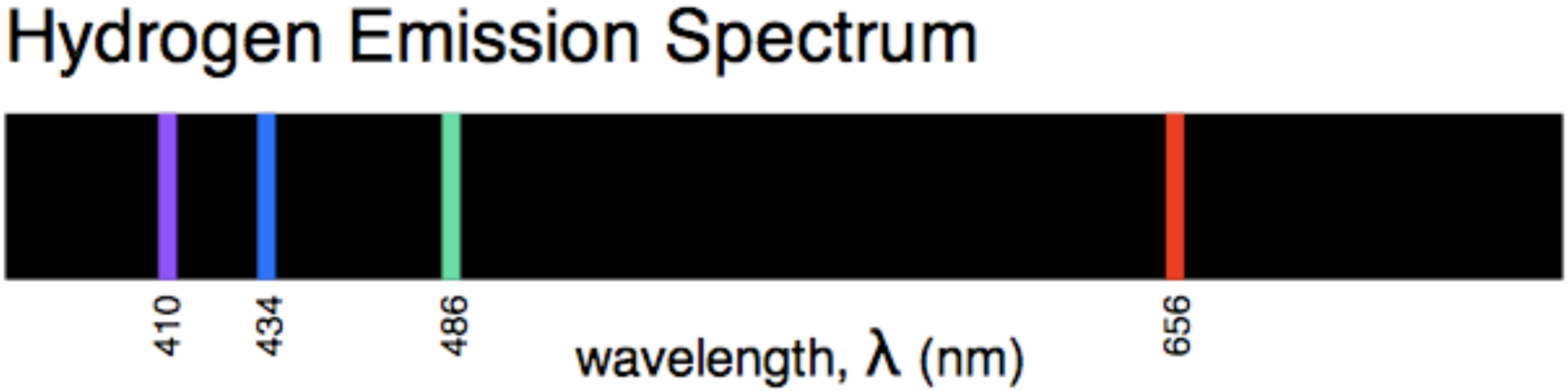
http://etc.usf.edu/clipart/36000/36046/spectroscope_36046.htm

HYDROGEN LAMP



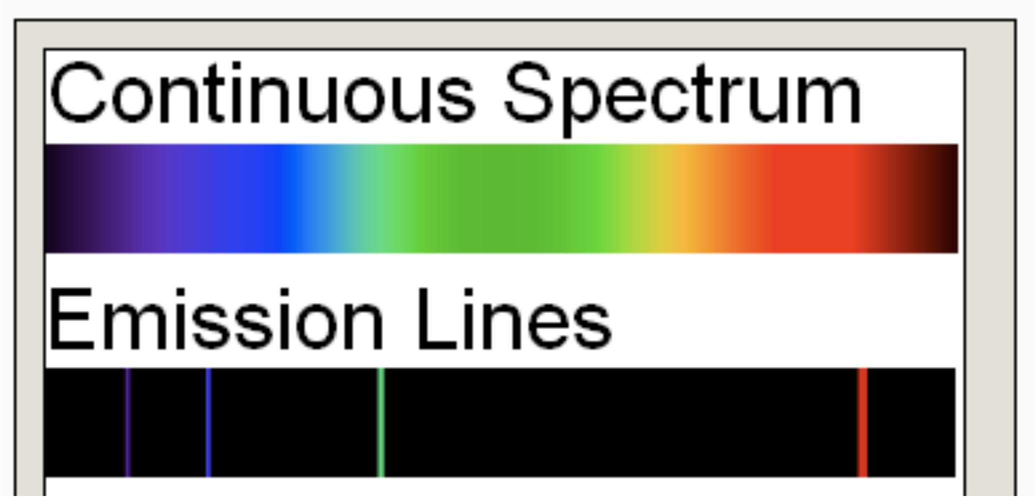
http://www1.assumption.edu/users/bniece/spectra/HiResolution/H2b.jpg

HYDROGEN EMISSION SPECTRUM



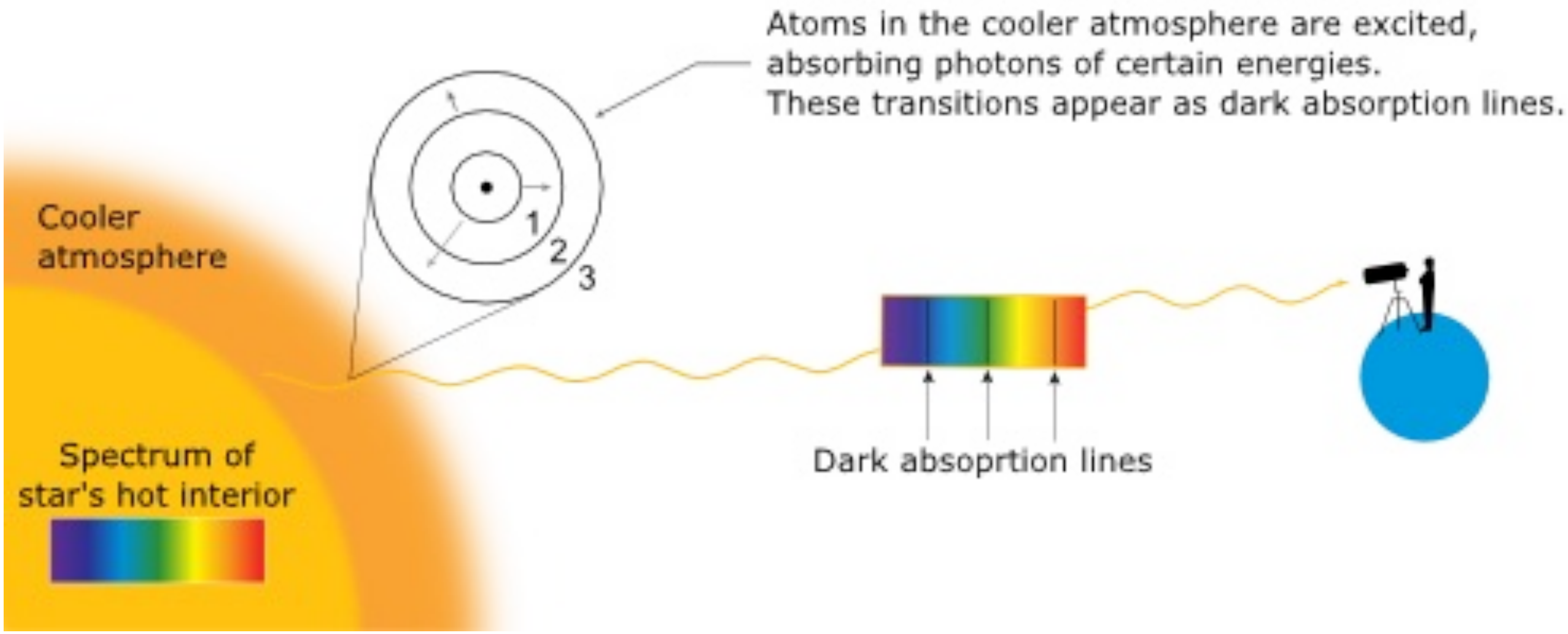
http://ch301.cm.utexas.edu/atomic/H-atom/H-atom-all.php

"WHITE LIGHT" VS HYDROGEN SPECTRUM



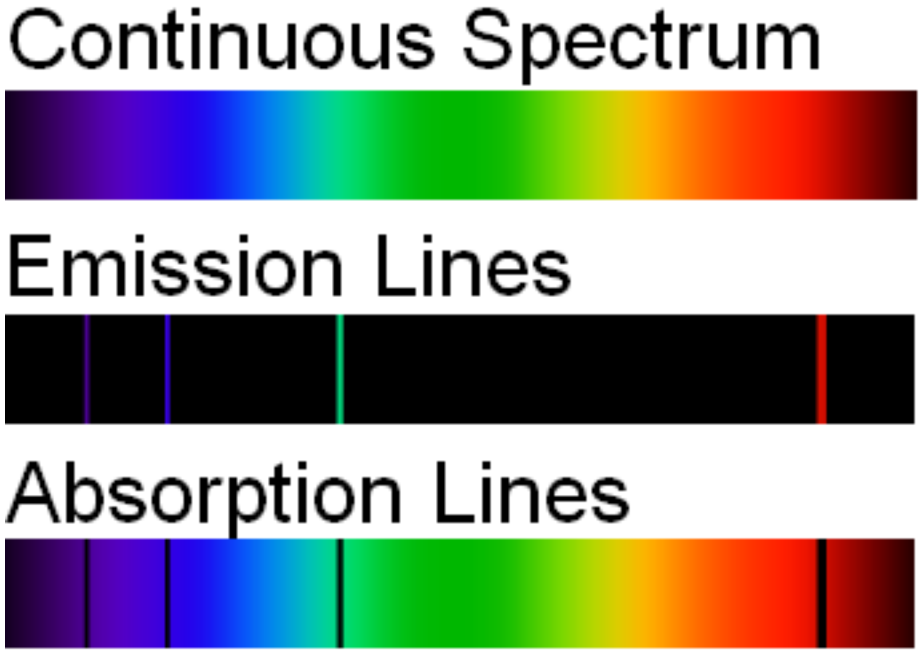
http://astro.unl.edu/naap/hr/hr_background1.html

ABSORPTION LINES



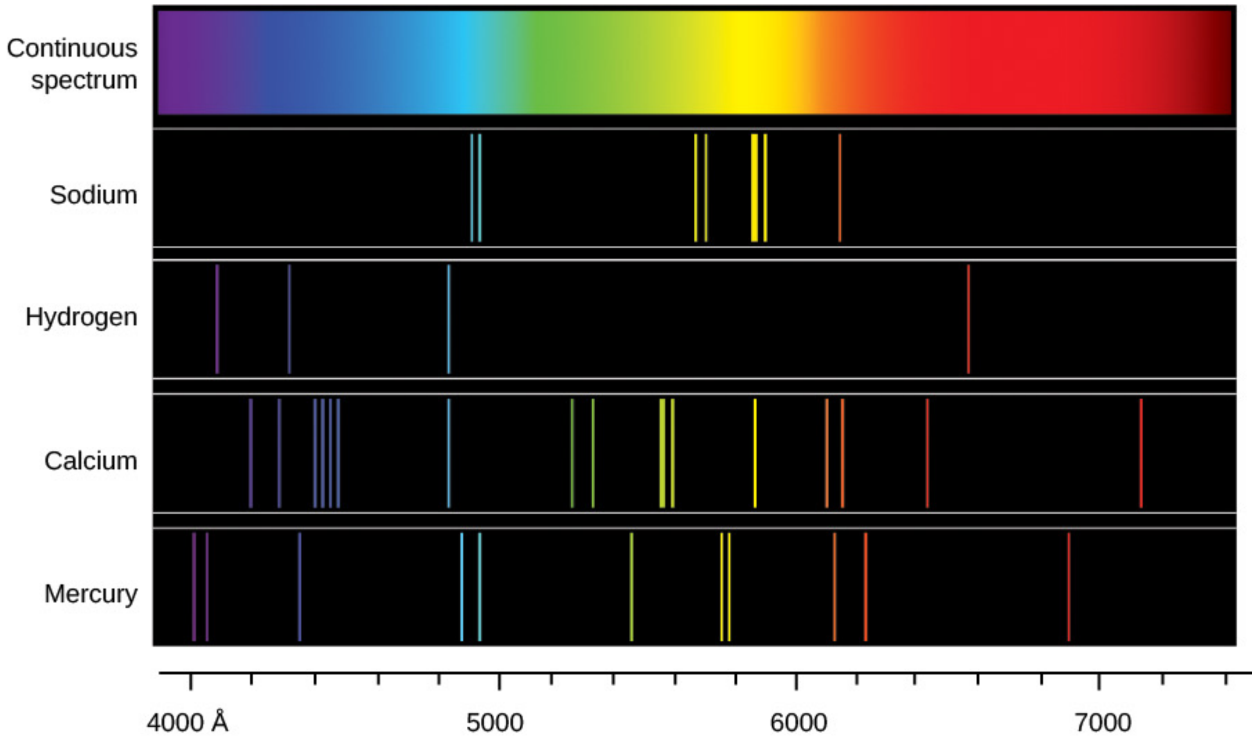
http://astro.unl.edu/naap/hr/hr_background1.html

COMPARISON OF EMISSION & ABSORPTION



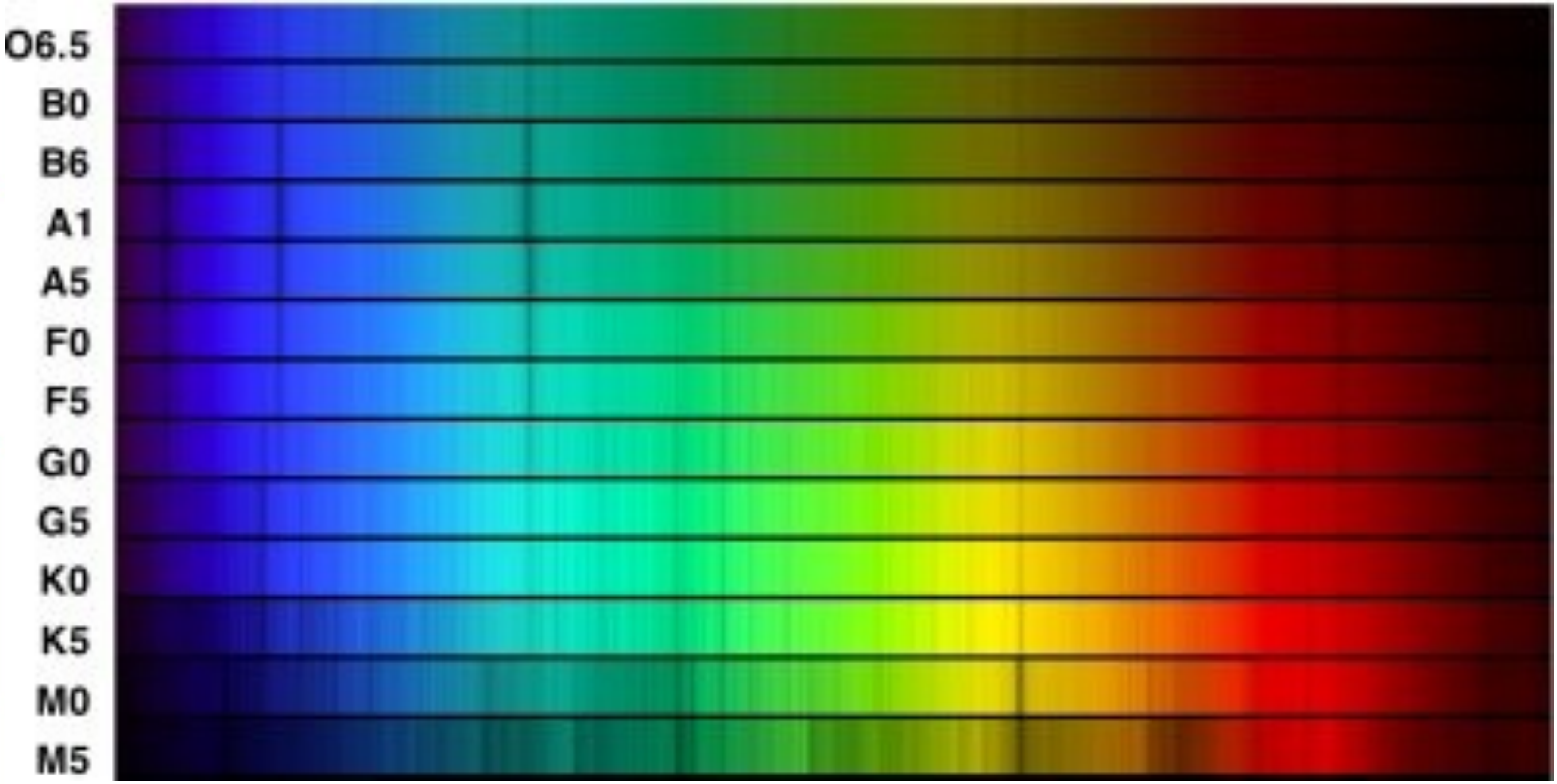
http://astro.unl.edu/naap/hr/hr_background1.html

FIGURE 5.12



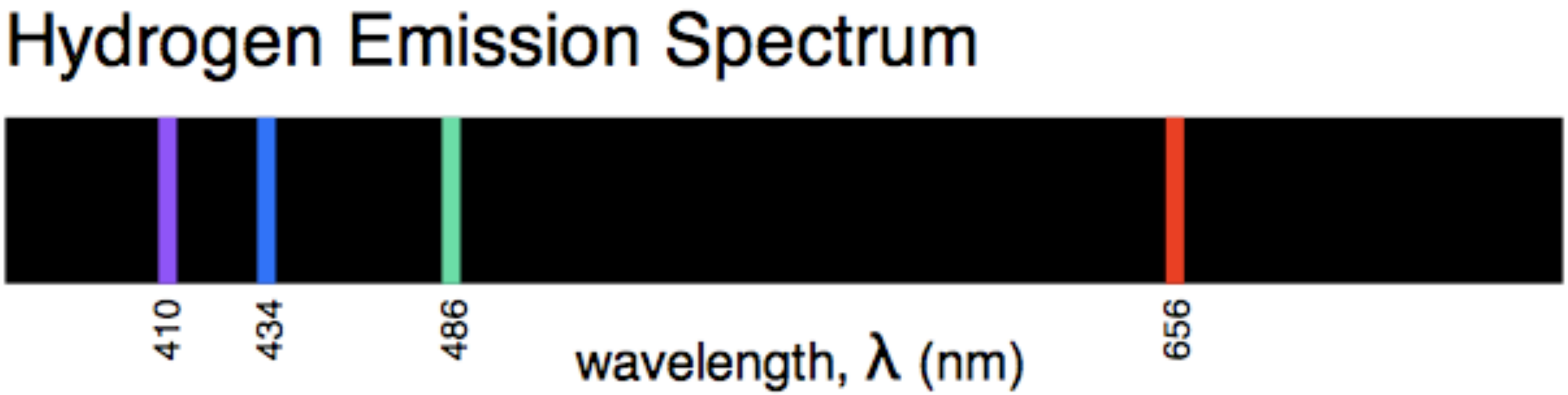
Continuous Spectrum and Line Spectra from Different Elements. Each type of glowing gas (each element) produces its own unique pattern of lines, so the composition of a gas can be identified by its spectrum. The spectra of sodium, hydrogen, calcium, and mercury gases are shown here.

SPECTRAL TYPE OF STARS



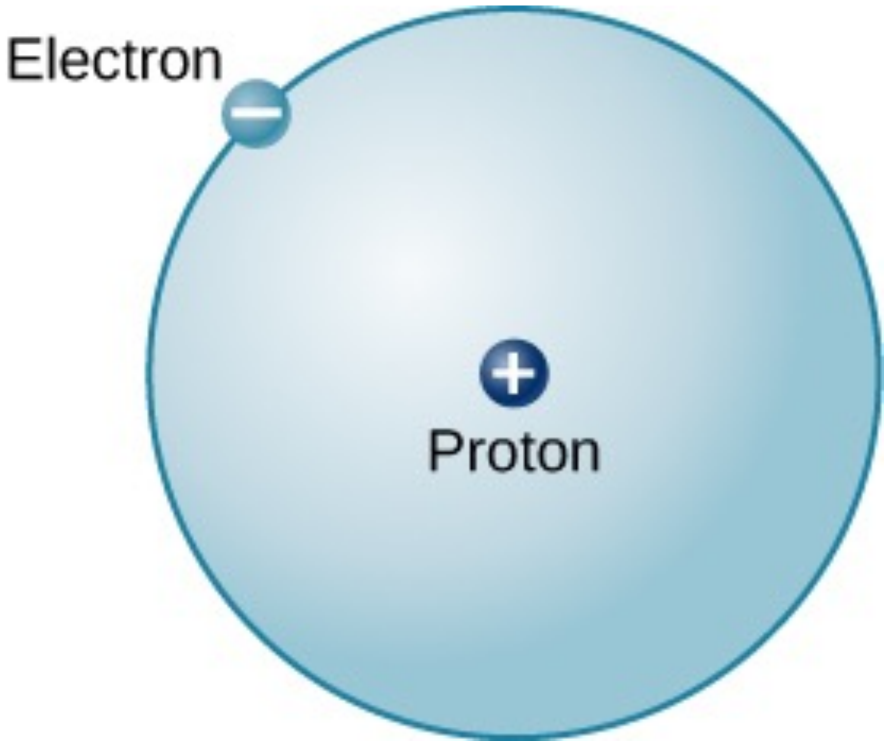
NOAO/AURA/NSF http://astro.unl.edu/naap/hr/hr_background1.html

HYDROGEN EMISSION SPECTRUM



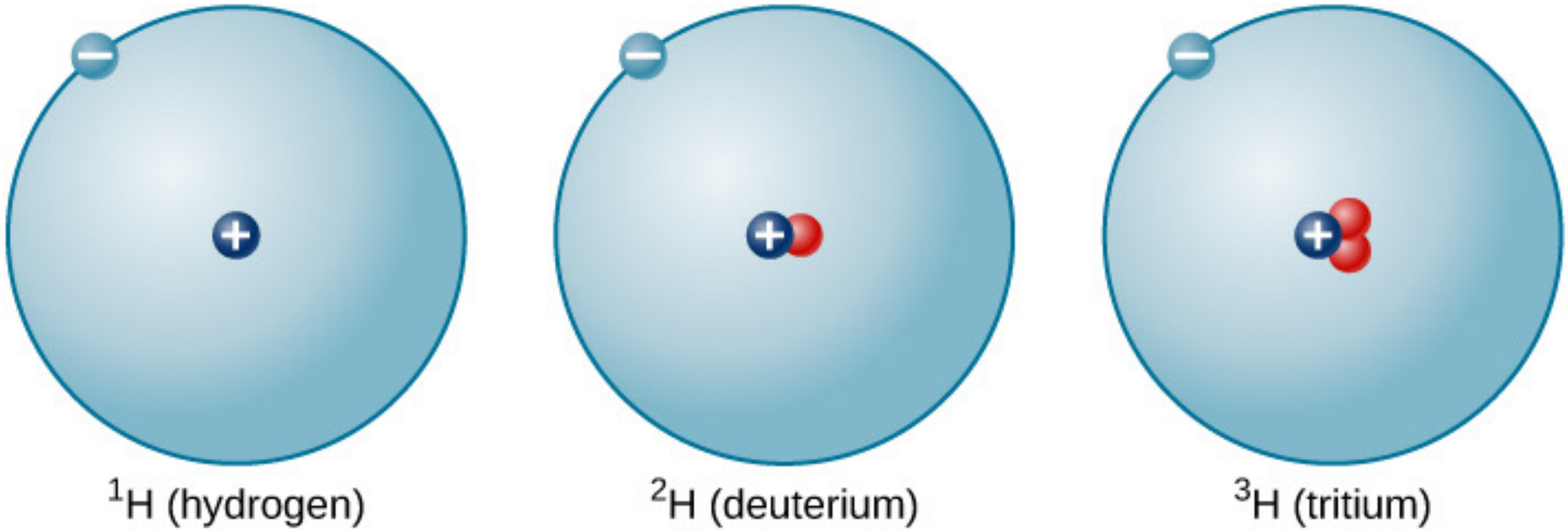
http://ch301.cm.utexas.edu/atomic/H-atom/H-atom-all.php

FIGURE 5.15



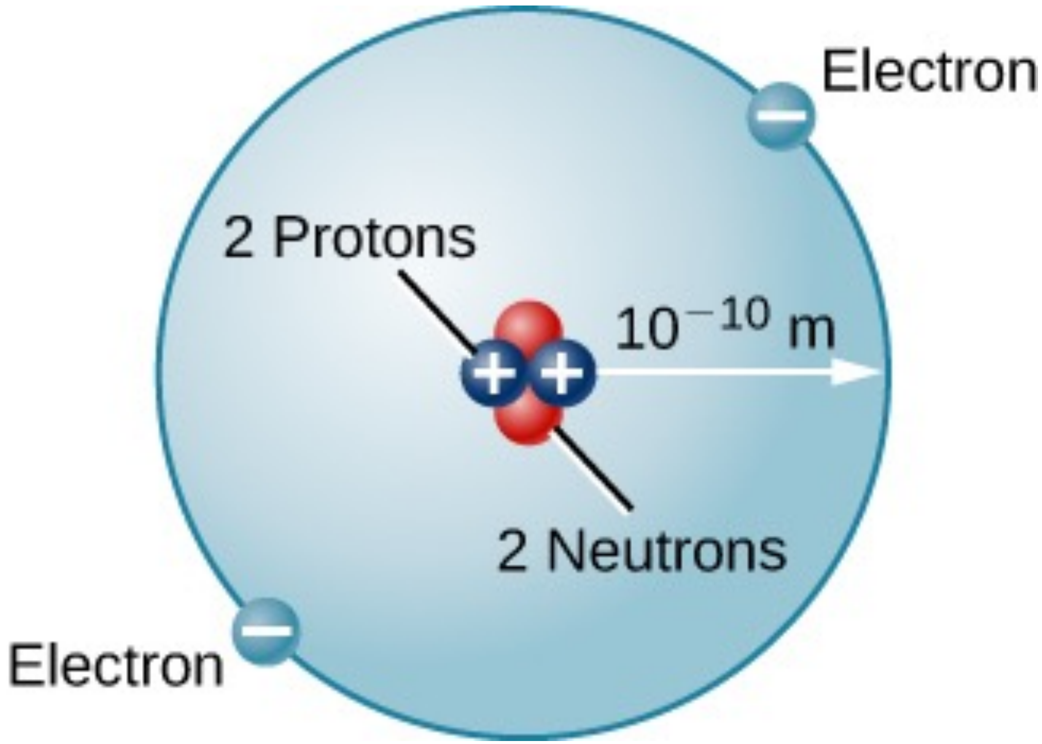
Hydrogen Atom. This is a schematic diagram of a hydrogen atom in its lowest energy state, also called the ground state. The proton and electron have equal but opposite charges, which exert an electromagnetic force that binds the hydrogen atom together. In the illustration, the size of the particles is exaggerated so that you can see them; they are not to scale. They are also shown much closer than they would actually be as it would take more than an entire page to show their actual distance to scale.

FIGURE 5.17



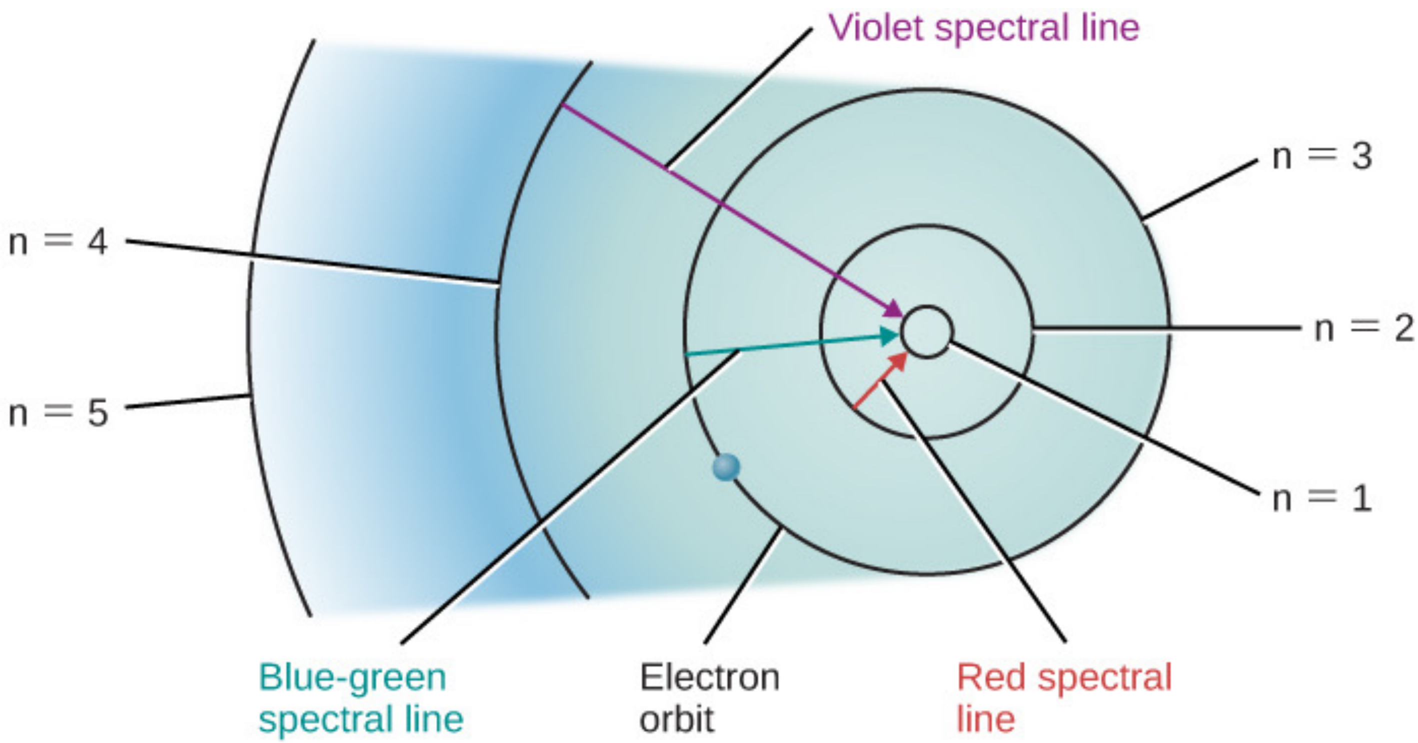
Isotopes of Hydrogen. A single proton in the nucleus defines the atom to be hydrogen, but there may be zero, one, or two neutrons. The most common isotope of hydrogen is the one with only a single proton and no neutrons.

FIGURE 5.16



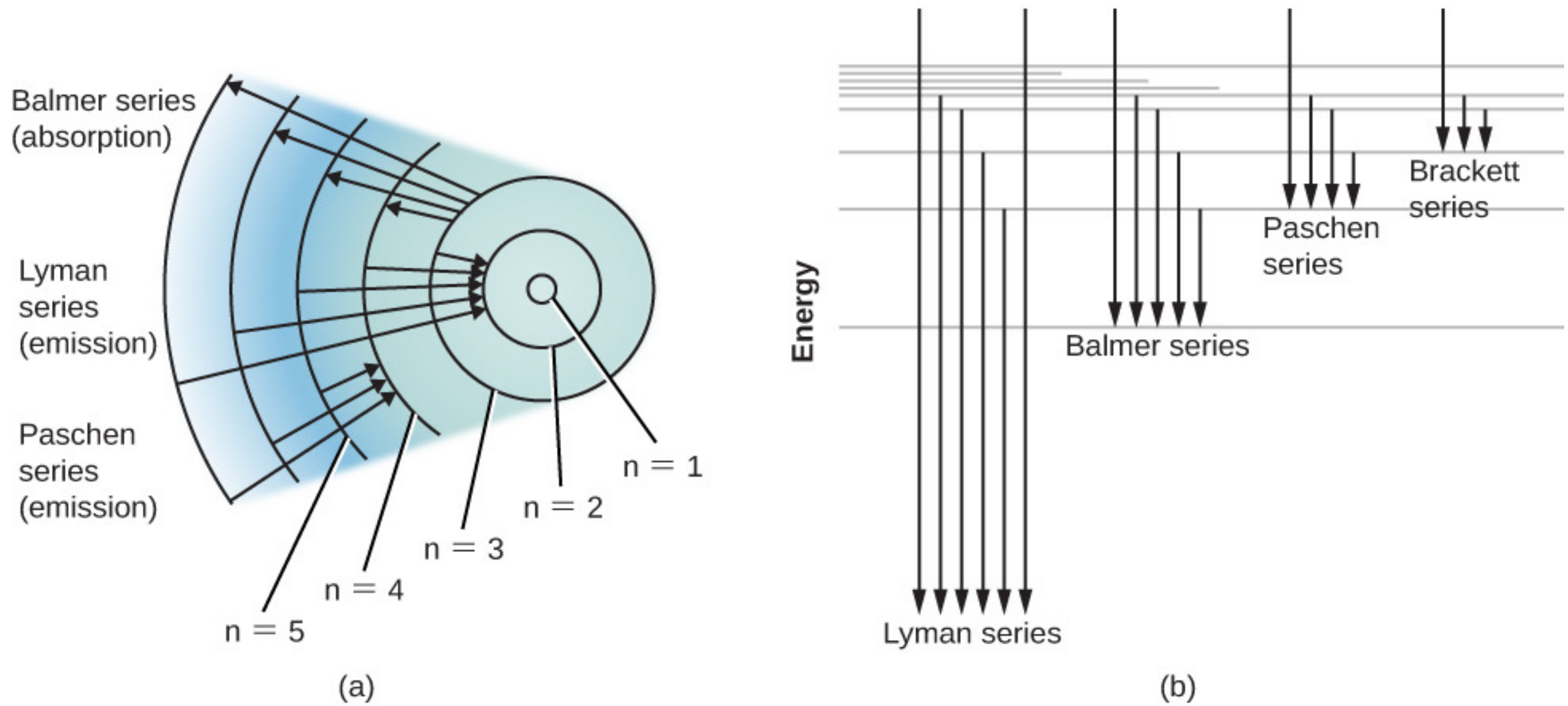
Helium Atom. Here we see a schematic diagram of a helium atom in its lowest energy state. Two protons are present in the nucleus of all helium atoms. In the most common variety of helium, the nucleus also contains two neutrons, which have nearly the same mass as the proton but carry no charge. Two electrons orbit the nucleus.

FIGURE 5.19



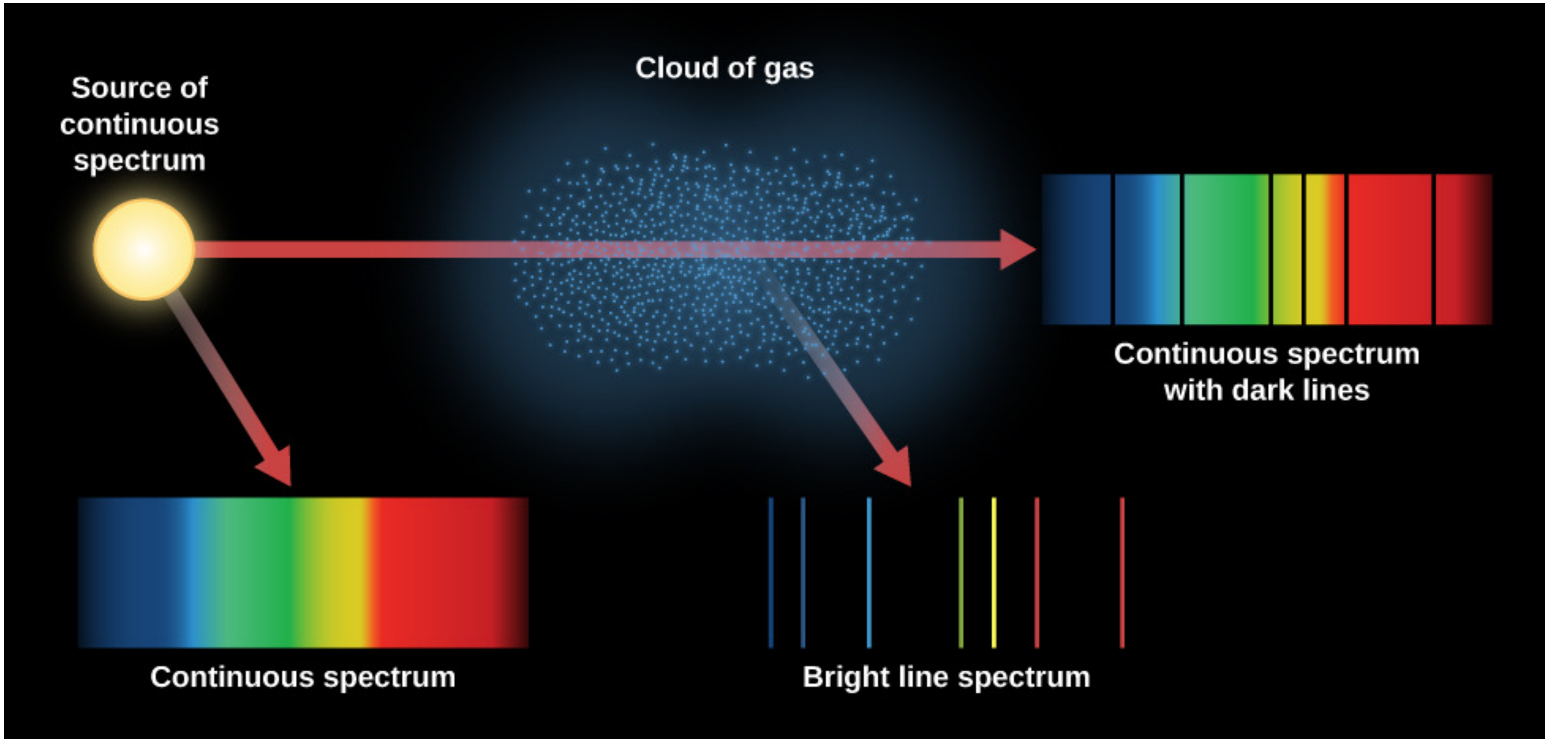
Bohr Model for Hydrogen. In this simplified model of a hydrogen atom, the concentric circles shown represent permitted orbits or energy levels. An electron in a hydrogen atom can only exist in one of these energy levels (or states). The closer the electron is to the nucleus, the more tightly bound the electron is to the nucleus. By absorbing energy, the electron can move to energy levels farther from the nucleus (and even escape if enough energy is absorbed).

FIGURE 5.20



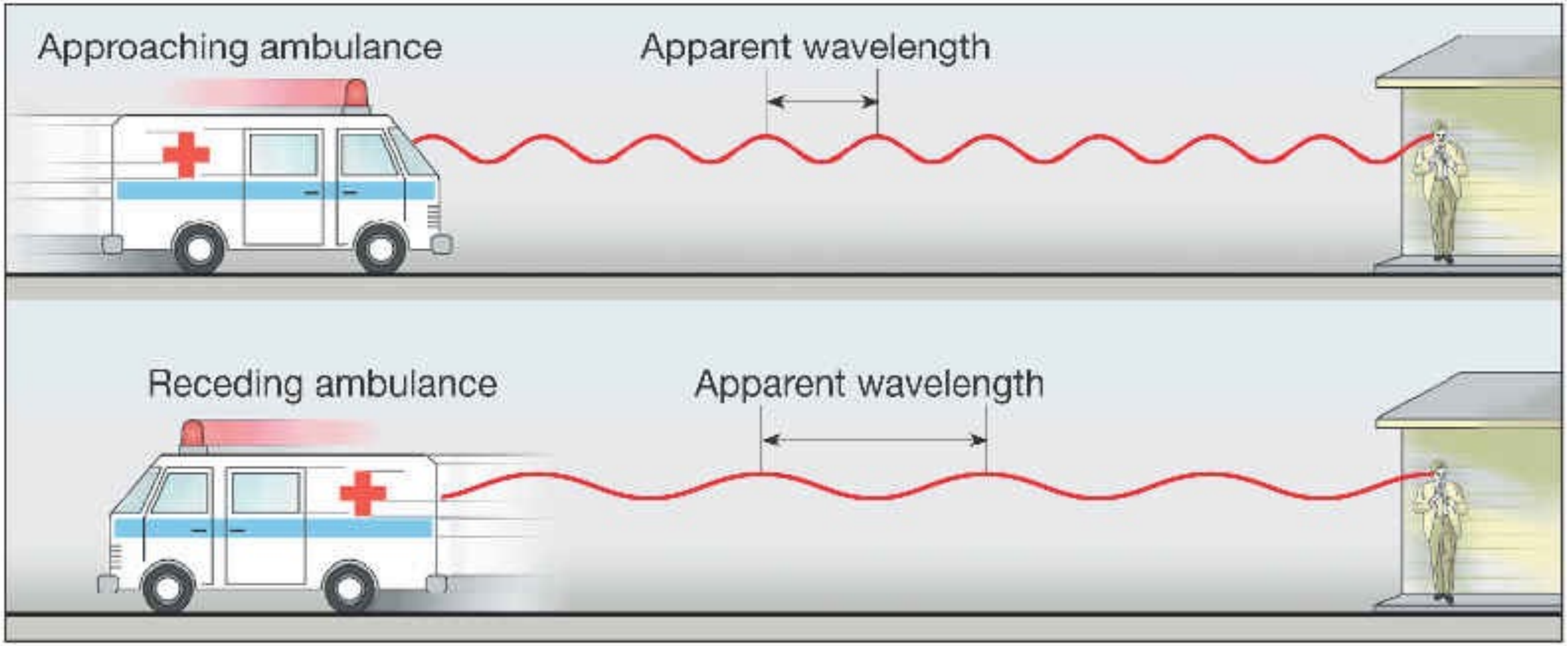
Energy-Level Diagrams for Hydrogen. (a) Here we follow the emission or absorption of photons by a hydrogen atom according to the Bohr model. Several different series of spectral lines are shown, corresponding to transitions of electrons from or to certain allowed orbits. Each series of lines that terminates on a specific inner orbit is named for the physicist who studied it. At the top, for example, you see the Balmer series, and arrows show electrons jumping from the second orbit ($n = 2$) to the third, fourth, fifth, and sixth orbits. Each time a “poor” electron from a lower level wants to rise to a higher position in life, it must absorb energy to do so. It can absorb the energy it needs from passing waves (or photons) of light. The next set of arrows (Lyman series) show electrons falling down to the first orbit from different (higher) levels. Each time a “rich” electron goes downward toward the nucleus, it can afford to give off (emit) some energy it no longer needs. (b) At higher and higher energy levels, the levels become more and more crowded together, approaching a limit. The region above the top line represents energies at which the atom is ionized (the electron is no longer attached to the atom). Each series of arrows represents electrons falling from higher levels to lower ones, releasing photons or waves of energy in the process.

FIGURE 5.21



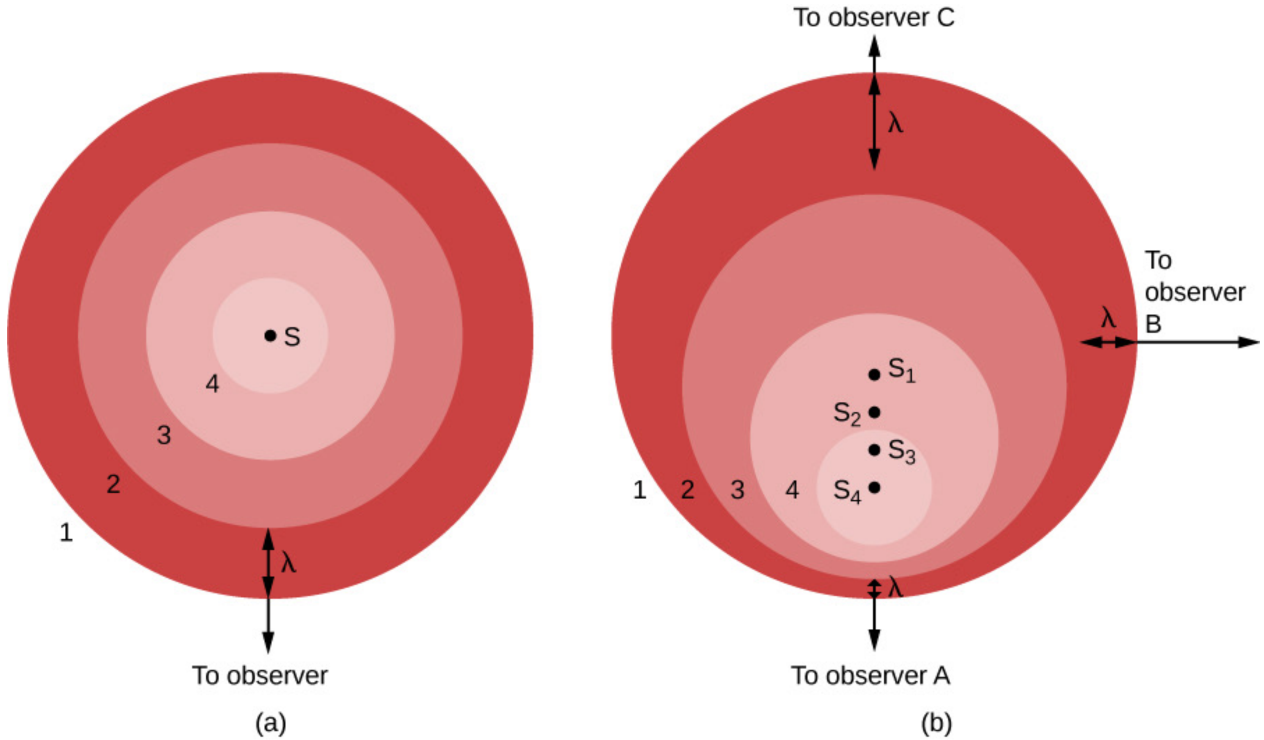
Three Kinds of Spectra. When we see a lightbulb or other source of continuous radiation, all the colors are present. When the continuous spectrum is seen through a thinner gas cloud, the cloud's atoms produce absorption lines in the continuous spectrum. When the excited cloud is seen without the continuous source behind it, its atoms produce emission lines. We can learn which types of atoms are in the gas cloud from the pattern of absorption or emission lines.

THE DOPPLER EFFECT



http://www.geography.hunter.cuny.edu/tbw/wc.notes/10.thunderstorms.tornadoes/doppler_effect.htm

FIGURE 5.22



Doppler Effect.

(a) A source, S, makes waves whose numbered crests (1, 2, 3, and 4) wash over a stationary observer.

(b) The source S now moves toward observer *A* and away from observer *C*. Wave crest 1 was emitted when the source was at position S4, crest 2 at position S2, and so forth. Observer *A* sees waves compressed by this motion and sees a blueshift (if the waves are light). Observer *C* sees the waves stretched out by the motion and sees a redshift. Observer *B*, whose line of sight is perpendicular to the source's motion, sees no change in the waves (and feels left out).

DOPPLER SHIFTED SPECTRAL LINES

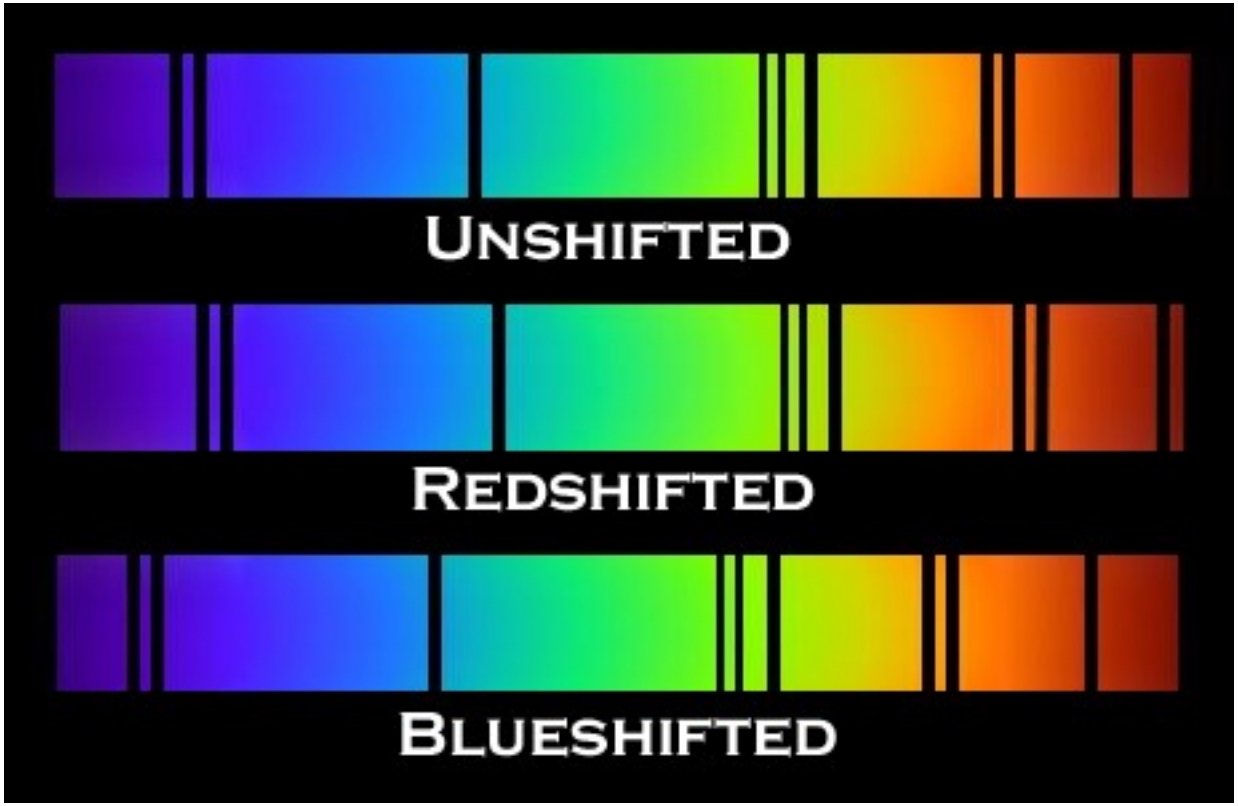


Image credit: [Text copyright 1992-2007 Robert W. O'Connell.]

http://www.astro.cornell.edu/share/sharvari/websiteV7/infofromlines.htm

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Typeset using LATEX twocolumn style in AASTeX62

Water Vapor on the Habitable-Zone Exoplanet K2-18b

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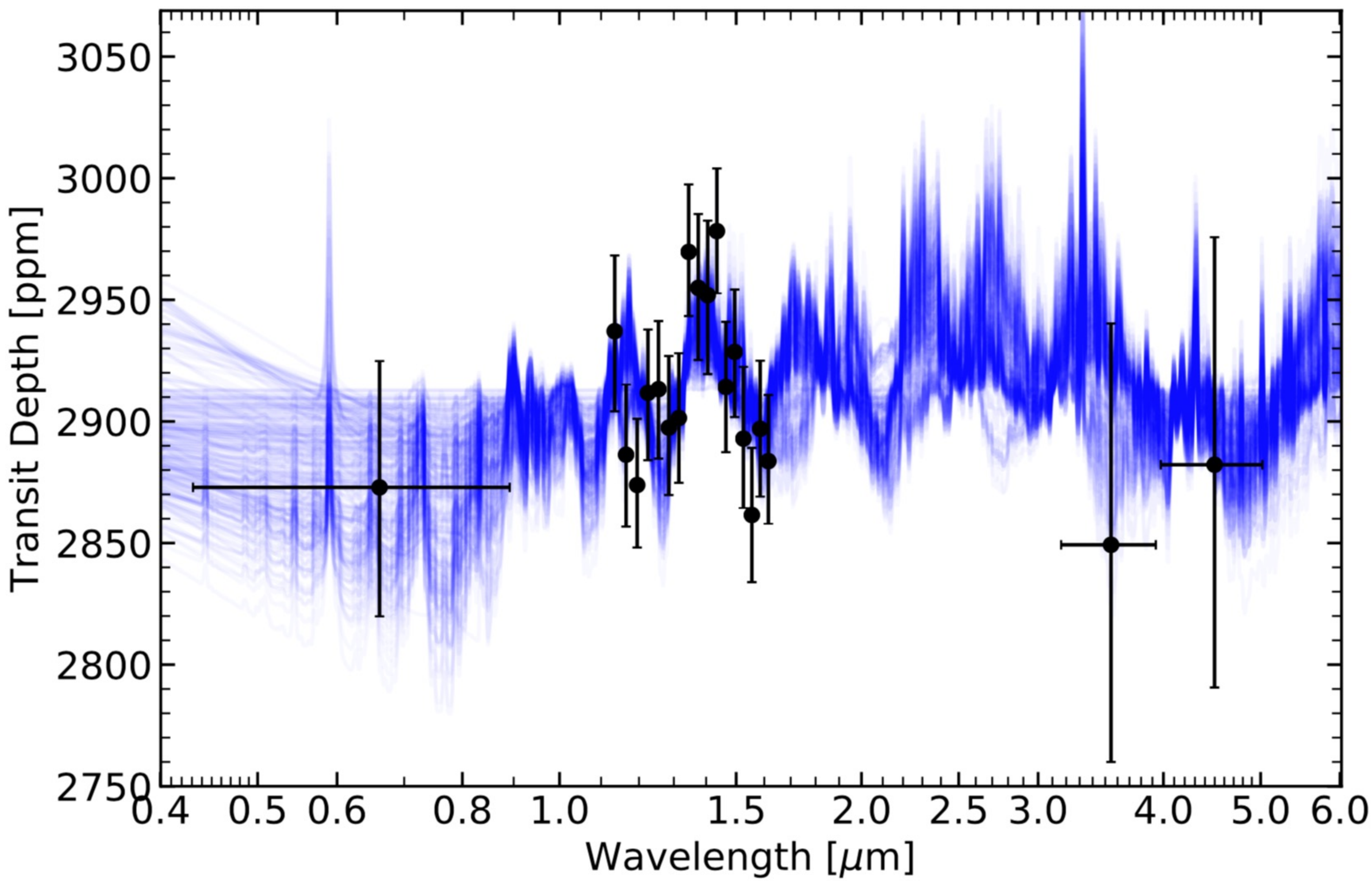
Jonathan J. Fortney,[14] and Jonathan Fraine[15]

ABSTRACT

Ever since the discovery of the first exoplanet, astronomers have made steady progress towards finding and probing planets in the habitable zone of their host stars, where the conditions could be right for liquid water to form and life to sprawl. Results from the Kepler mission indicate that the occurrence rate of habitable-zone Earths and super-Earths may be as high as 5–20%. Despite this abundance, probing the conditions and atmospheric properties on any of these habitable-zone planets is extremely difficult and has remained elusive to date. Here, we report the detection of water vapor and the likely presence of liquid water clouds in the atmosphere of the 8.6 $M_\oplus$ habitable-zone planet K2-18b. With a 33 day orbit around a cool M3 dwarf, K2-18b receives virtually the same amount of total radiation from its host star (1441 ± 80 W/m^2) as the Earth receives from the Sun (1370 W/m^2), making it a good candidate to host liquid water clouds. In this study we observed eight transits using HST/WFC3 in order to achieve the necessary sensitivity to detect water vapor. While the thick gaseous envelope of K2-18b means that it is not a true Earth analogue, our observations demonstrate that low-mass habitable-zone planets with the right conditions for liquid water are accessible with state-of-the-art telescopes.

Water Vapor on the Habitable-Zone Exoplanet K2-18



https://arxiv.org/pdf/1909.04642.pdf

SUMMARY

- **the different parts of the electromagnetic spectrum** (e.g. light, radio, X-rays)
- **the relationship between wavelength, frequency and period of a wave**
- **the structure of atoms**
  - negatively charged electrons around positively charged protons and neutral neutrons in the nucleus
  - how atoms produce light
  - electrons changing energy levels in their "orbits" about the nucleus
- **the blackbody spectrum**, and how the wavelength changes with temperature
- **the Doppler Effect**