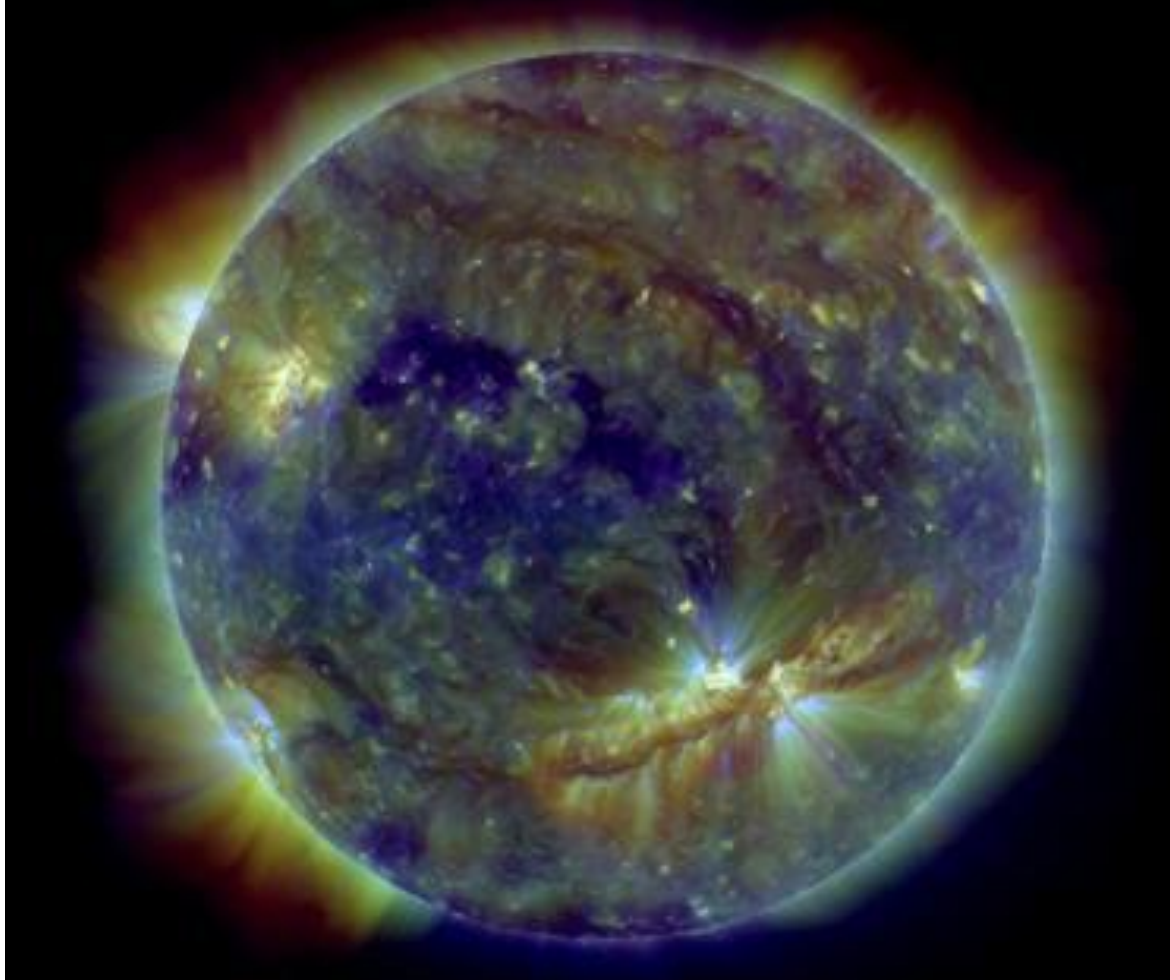


FIGURE 5.1

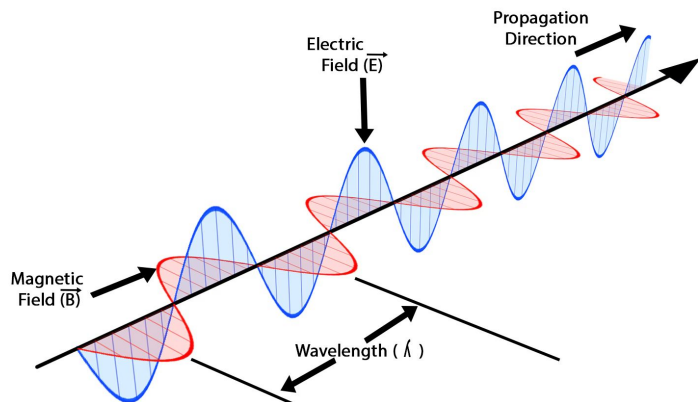


Our Sun in Ultraviolet Light. This photograph of the Sun was taken at several different wavelengths of ultraviolet, which our eyes cannot see, and then color coded so it **reveals activity in our Sun's atmosphere that cannot be observed in visible light.** This is why it is important to observe the Sun and other astronomical objects in wavelengths other than the visible band of the spectrum. This image was taken by a satellite from above Earth's atmosphere, which is necessary since Earth's atmosphere absorbs much of the ultraviolet light coming from space. (credit: modification of work by NASA)

FIGURE 5.2



Electromagnetic Wave



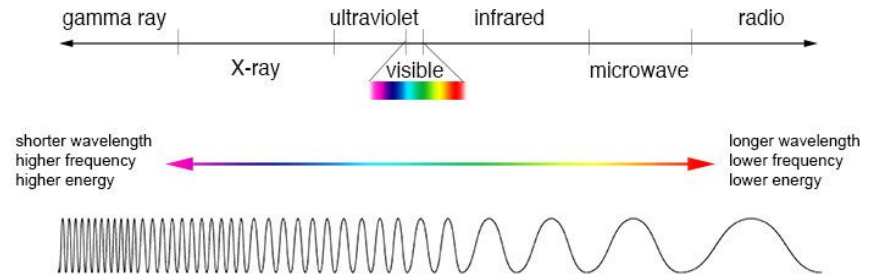
James Clerk Maxwell (1831–1879). Maxwell unified the rules governing electricity and magnetism into a coherent theory.

Understanding of light:

Maxwell's theory provided a fundamental understanding of the nature of light, paving the way for further developments in **optics** and electromagnetics.

Electromagnetic waves:

Maxwell predicted the existence of electromagnetic waves, which are oscillating electric and magnetic fields propagating through space at the **speed of light**



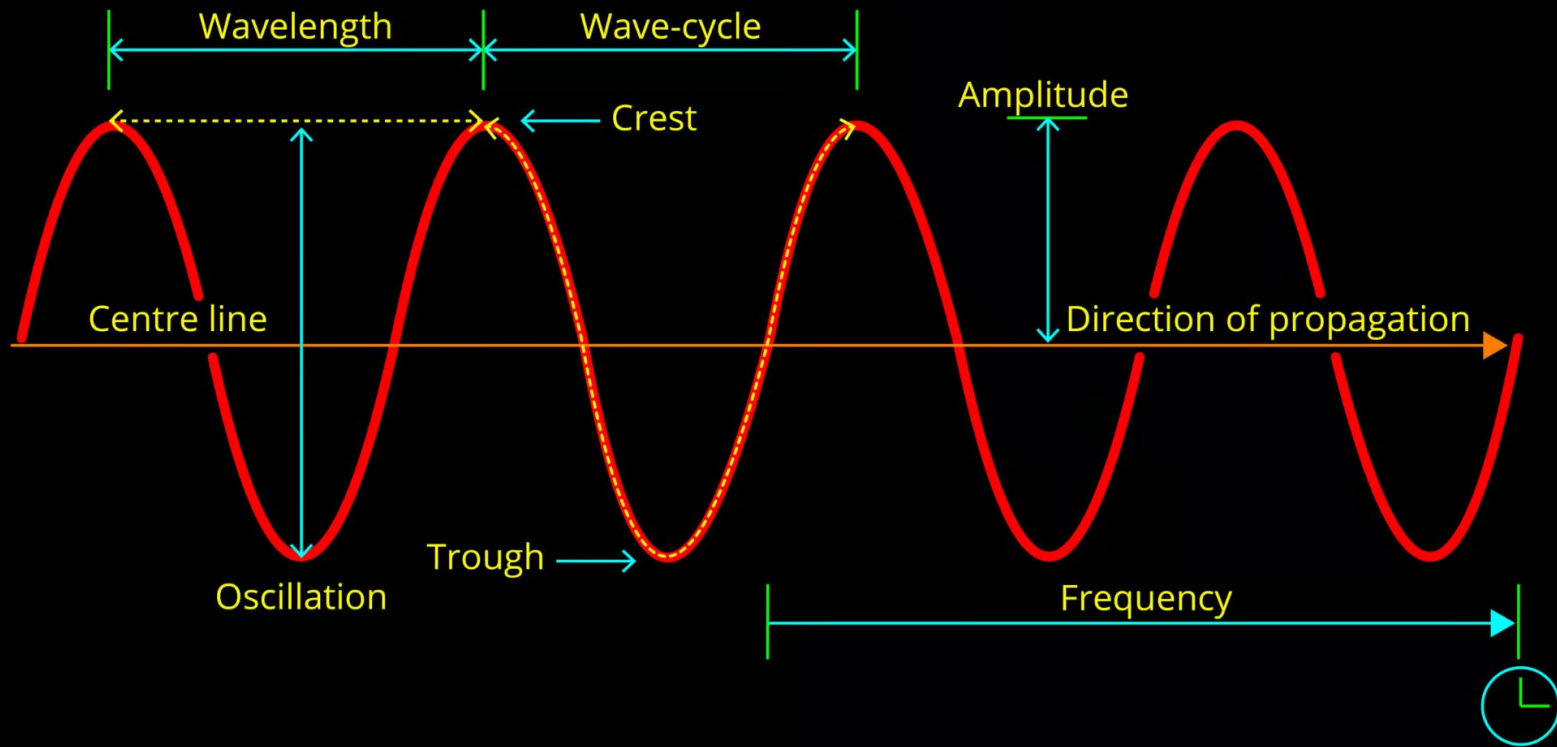
Electromagnetic radiation can be described in terms of a stream of mass-less particles, called **photons**, each traveling in a wave-like pattern at the speed of light. Each photon contains a certain amount of energy.

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)

FEATURES OF ELECTROMAGNETIC WAVES



Wavelength: The distance between successive crests of a wave

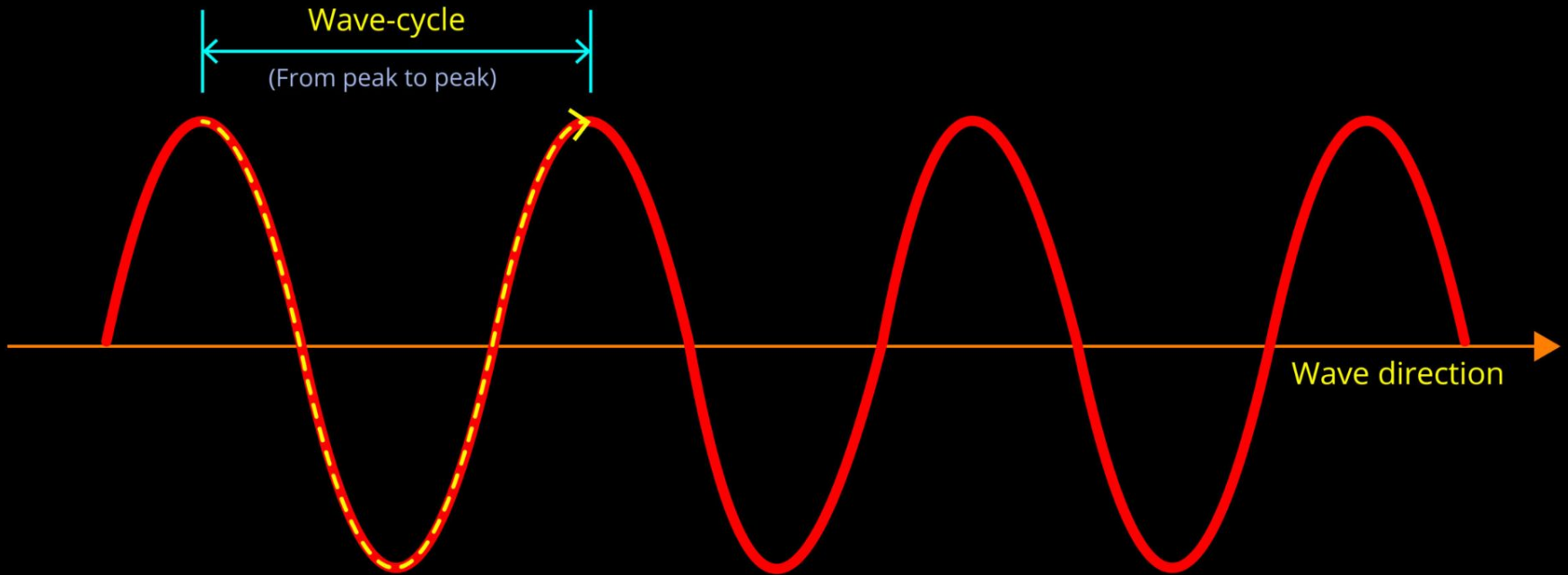
Frequency: Wave cycles passing a given point in a given period of time

Amplitude: Measured between the crest and the mid-point of a wave

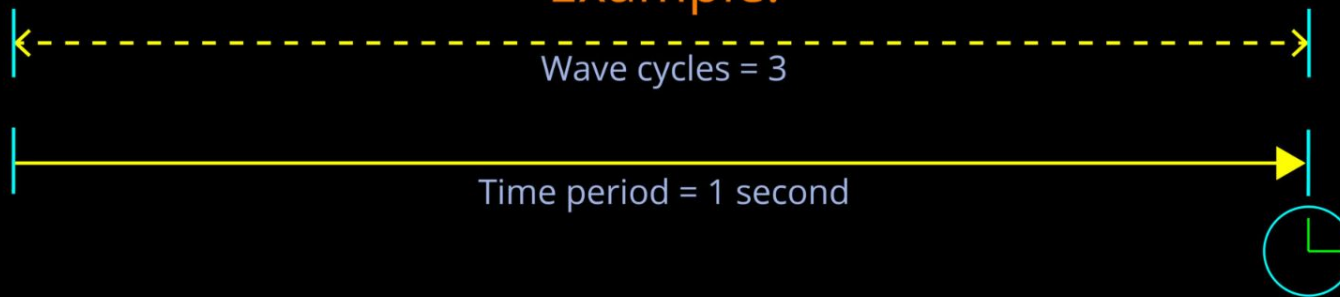
Velocity: Speed and direction of propagation

FIGURE 5.4 Legend: 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).

FREQUENCY OF ELECTROMAGNETIC WAVES

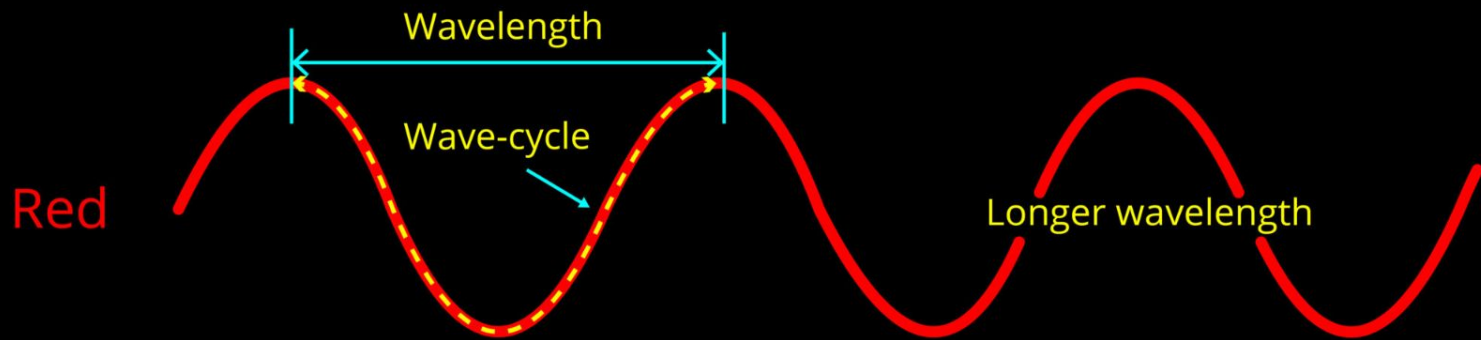


Example:

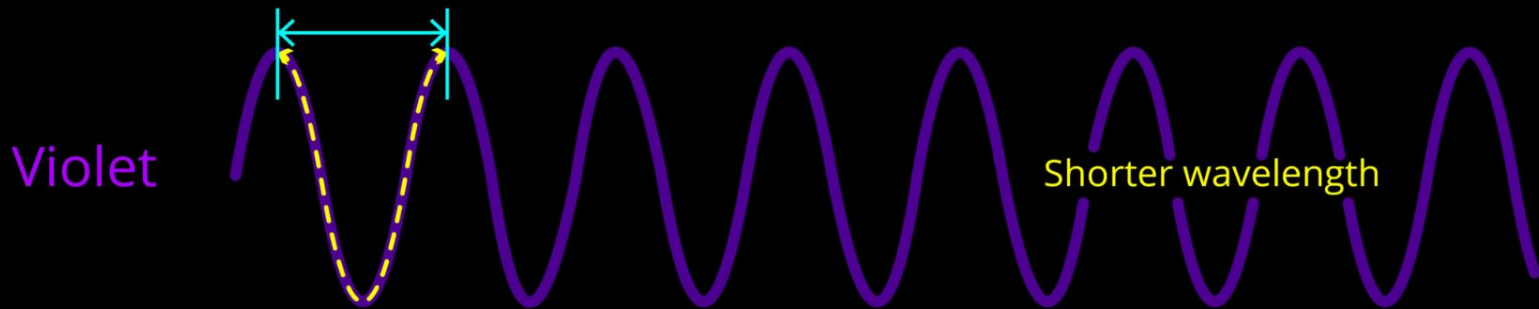


Frequency = 3 cycles per second = 3 Hertz

COMPARING WAVELENGTHS OF RED & VIOLET



Wavelength of Red = 700 nanometres
Wavelength of Violet = 450 nanometres



The unit of measurement for wavelength = metres

Millimetre (mm): 1,000 (thousand) millimetre = 1 metre

Micrometre (μm): 1,000,000 (million) micrometres = 1 metre

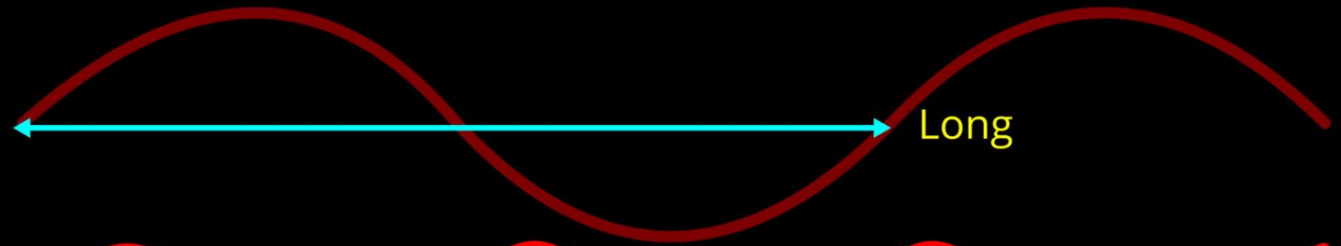
Nanometre (nm): 1,000,000,000 (billion) nanometres = 1 metre

Picometre (pm): 1,000,000,000,000 (trillion) picometres = 1 metre

What is a
nanometre?

COMPARING WAVELENGTHS - RADIO TO GAMMA

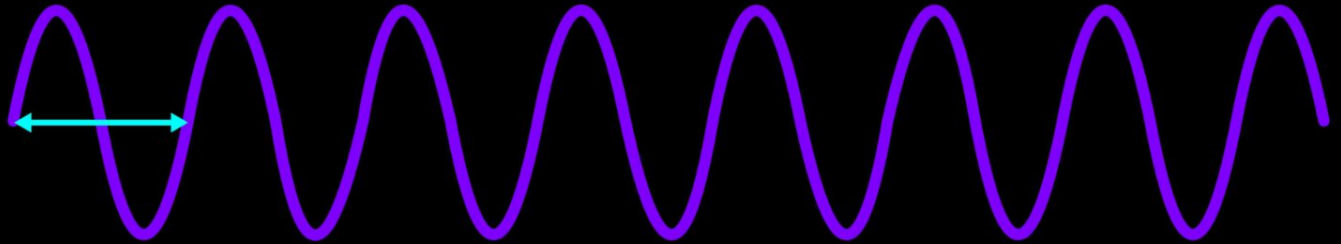
Radio waves
Kilometres (km)



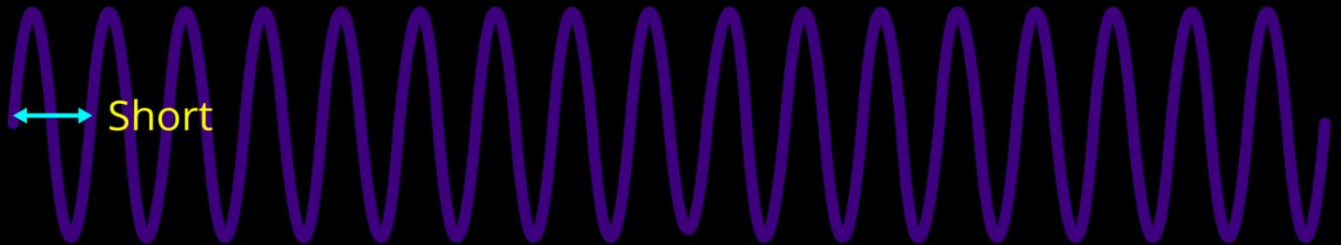
Red
Nanometres (nm)



Violet
Nanometres (nm)



Gamma ray
Picometres (pm)



Regions of the Electromagnetic Spectrum

Listed below are the approximate wavelength, frequency, and energy limits of the various regions of the electromagnetic spectrum.

	Wavelength (m)	Frequency (Hz)	Energy (J)
Radio	$> 1 \times 10^{-1}$	$< 3 \times 10^9$	$< 2 \times 10^{-24}$
Microwave	$1 \times 10^{-3} - 1 \times 10^{-1}$	$3 \times 10^9 - 3 \times 10^{11}$	$2 \times 10^{-24} - 2 \times 10^{-22}$
Infrared	$7 \times 10^{-7} - 1 \times 10^{-3}$	$3 \times 10^{11} - 4 \times 10^{14}$	$2 \times 10^{-22} - 3 \times 10^{-19}$
Optical	$4 \times 10^{-7} - 7 \times 10^{-7}$	$4 \times 10^{14} - 7.5 \times 10^{14}$	$3 \times 10^{-19} - 5 \times 10^{-19}$
UV	$1 \times 10^{-8} - 4 \times 10^{-7}$	$7.5 \times 10^{14} - 3 \times 10^{16}$	$5 \times 10^{-19} - 2 \times 10^{-17}$
X-ray	$1 \times 10^{-11} - 1 \times 10^{-8}$	$3 \times 10^{16} - 3 \times 10^{19}$	$2 \times 10^{-17} - 2 \times 10^{-14}$
Gamma-ray	$< 1 \times 10^{-11}$	$> 3 \times 10^{19}$	$> 2 \times 10^{-14}$

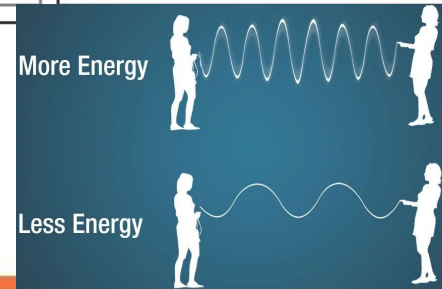
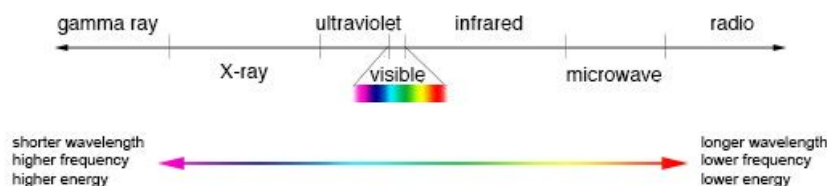


FIGURE 5.6

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)

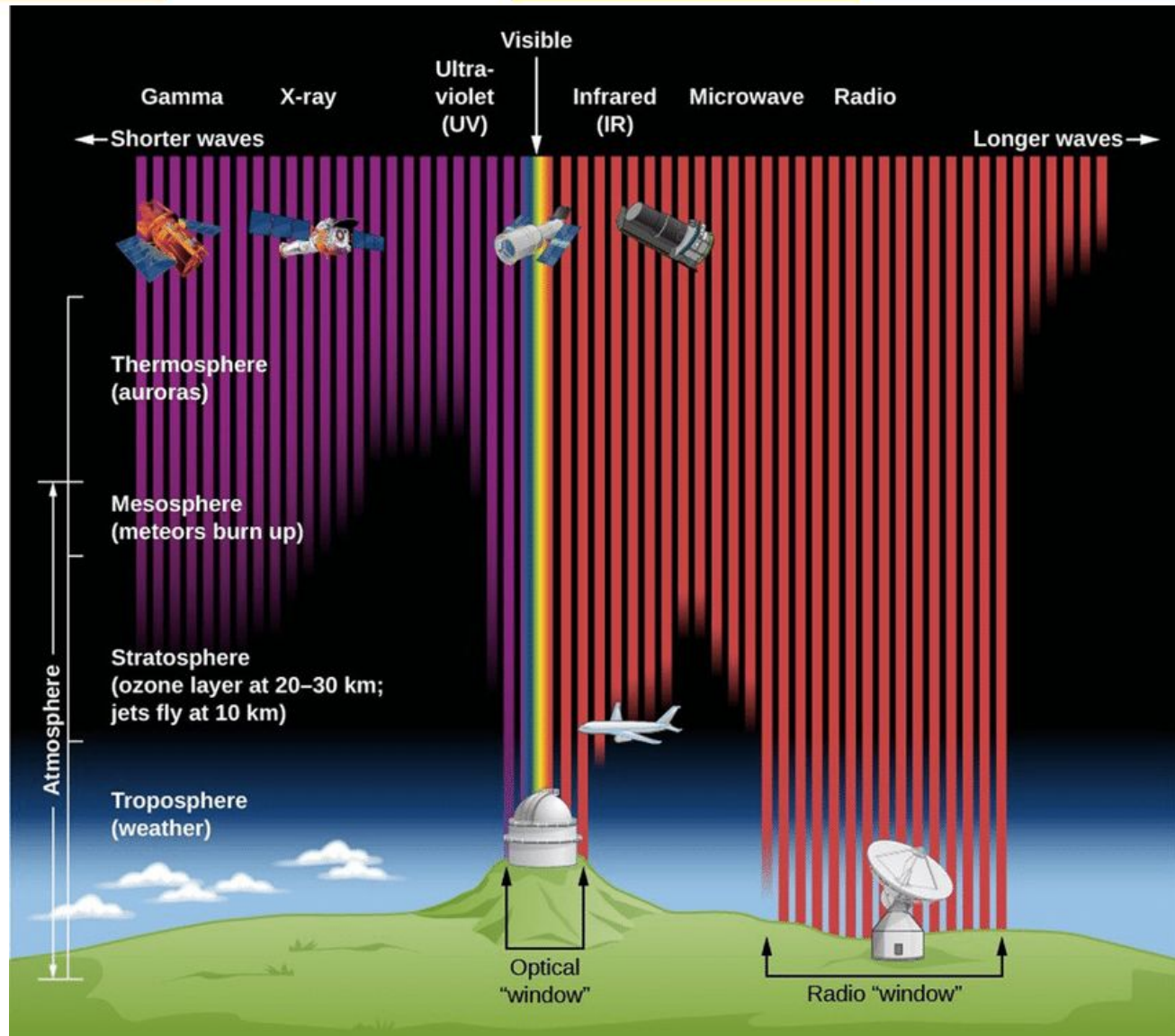
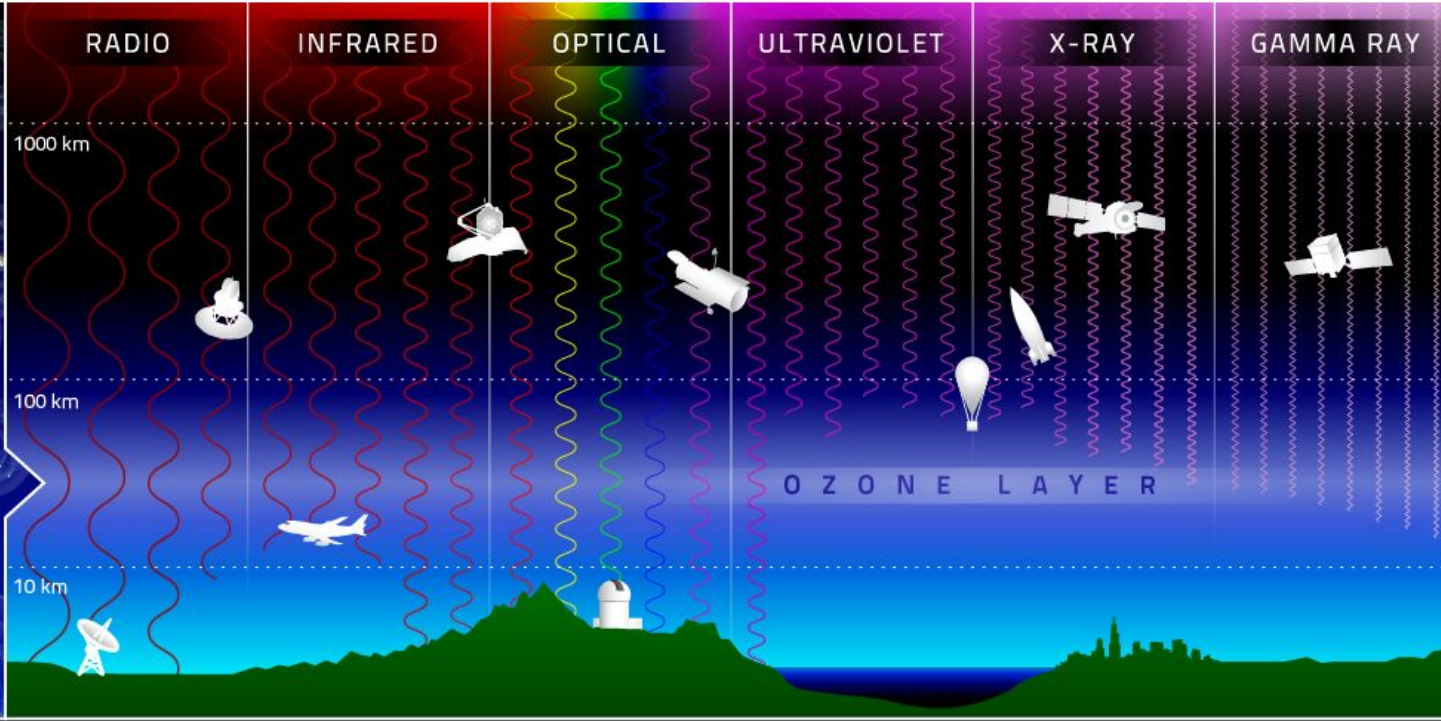


FIGURE 5.6 (Alternative)

MULTIWAVELENGTH LAND & SPACE BASED OBSERVATORIES

Molecules in the ozone layer of the atmosphere absorb high energy photons.

Most photons in the optical waveband are not absorbed, and parts of the ultraviolet, infrared, and radio wavebands also reach the ground.



The atmospheric effects on incoming light in each waveband determines the placement of telescopes.

Most of the Radio waveband is detectable using large dish antennae on the ground.

The infrared waveband can be detected from airplanes.

Ground telescopes observe most optical light, and some infrared and ultraviolet.

Balloons and rockets are used to test out new telescope technologies.

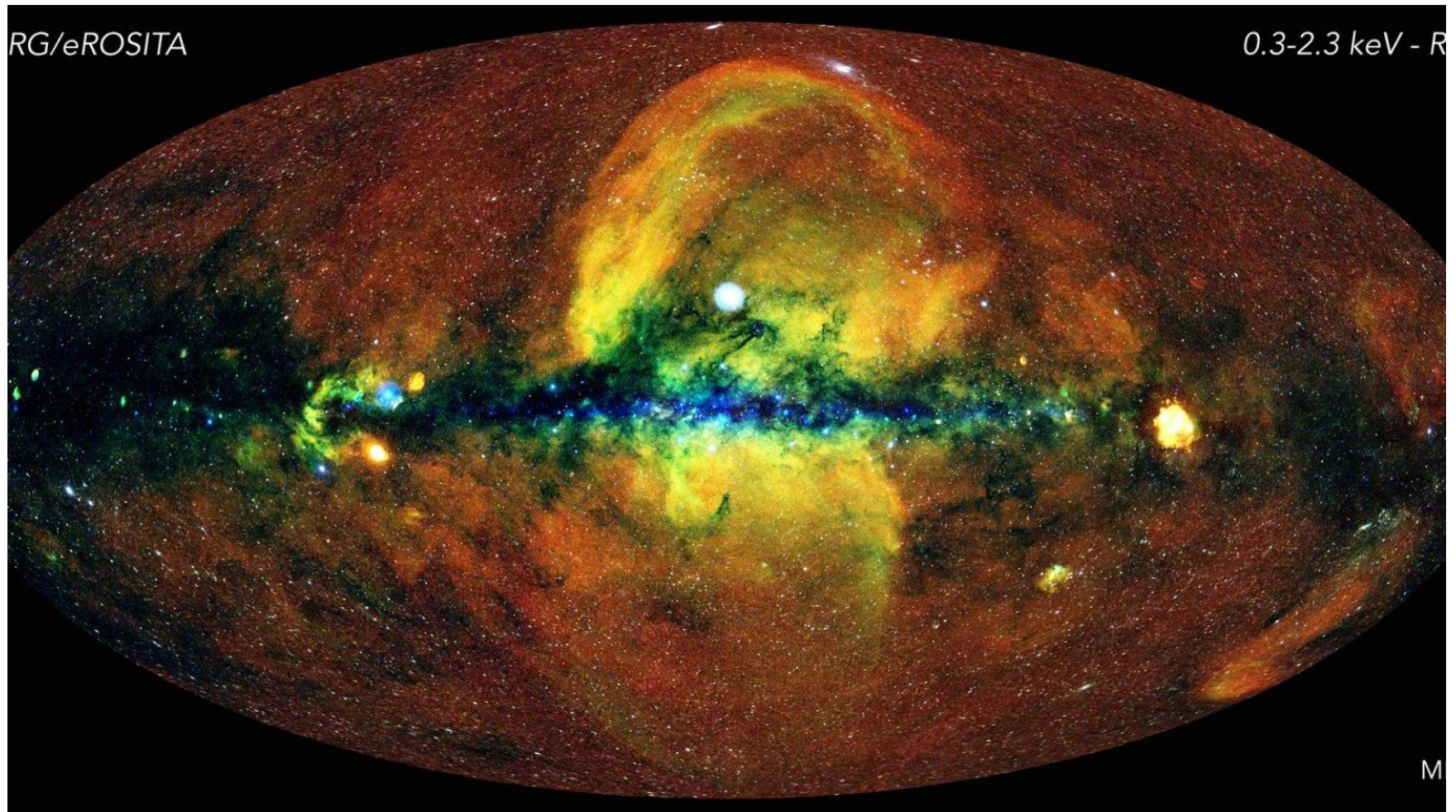
Space telescopes avoid atmospheric distortions and access high energy radiation.



In-Class Small Group Assignment

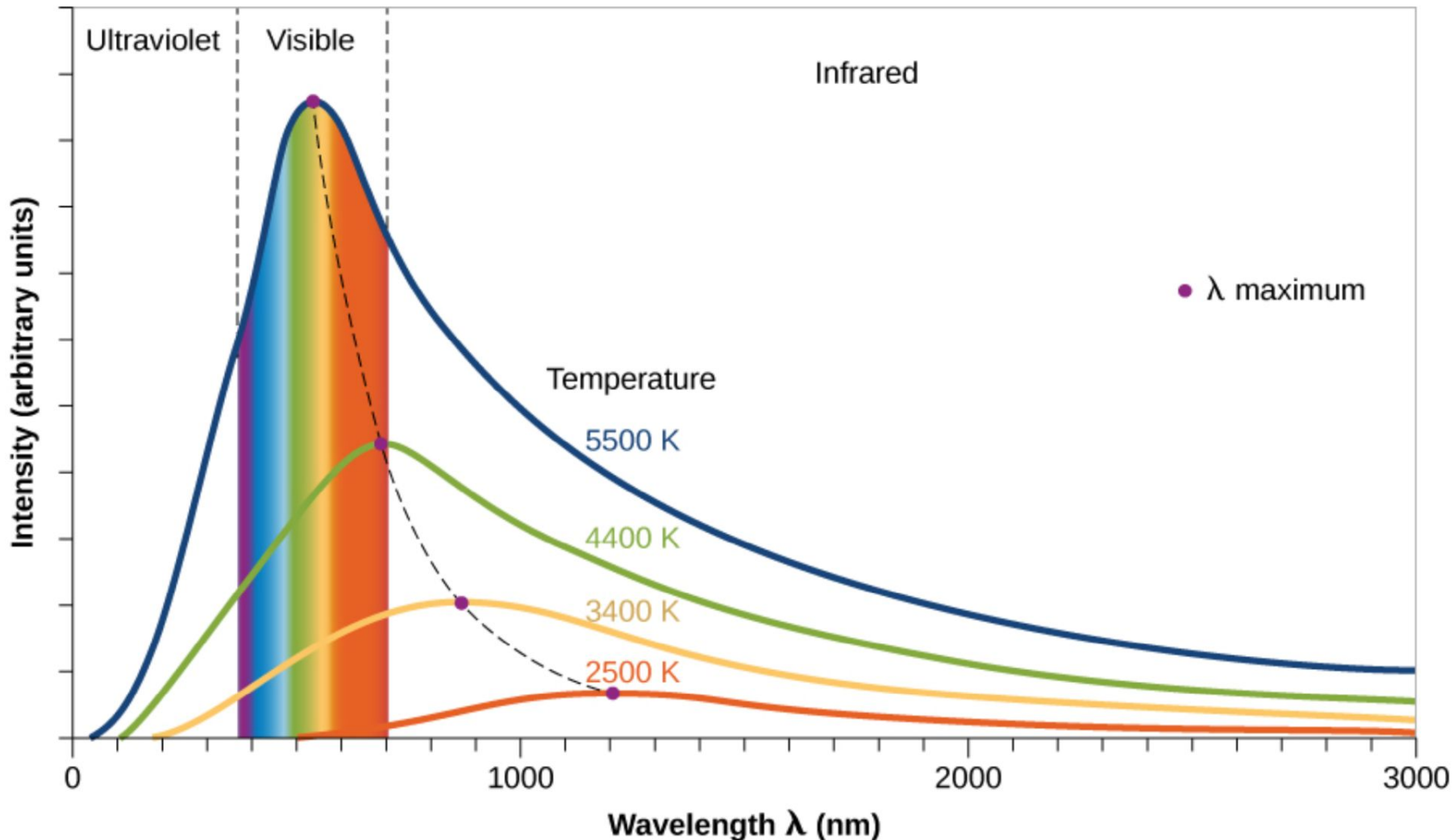
1. Form groups of 2-3 students
2. Create a shared “Google Doc” and share it with your professors too (LAndres@BU.edu and Henebry@BU.edu)
3. Include the names of all students on your small team in the body of the document.
4. **Suppose astronomers want to send a message to an alien civilization that is living on a planet with an atmosphere very similar to that of Earth's.**
5. **This message must travel through space, make it through the other planet's atmosphere, and be noticeable to the residents of that planet.**
6. **Discuss what band of the electromagnetic spectrum might be best for this message and why.**
7. **Also some people, including noted physicist Stephen Hawking, have warned scientists not to send such messages and reveal the presence of our civilization to a possible hostile cosmos. Do you agree with this concern?**

Another version of FIGURE 5.7



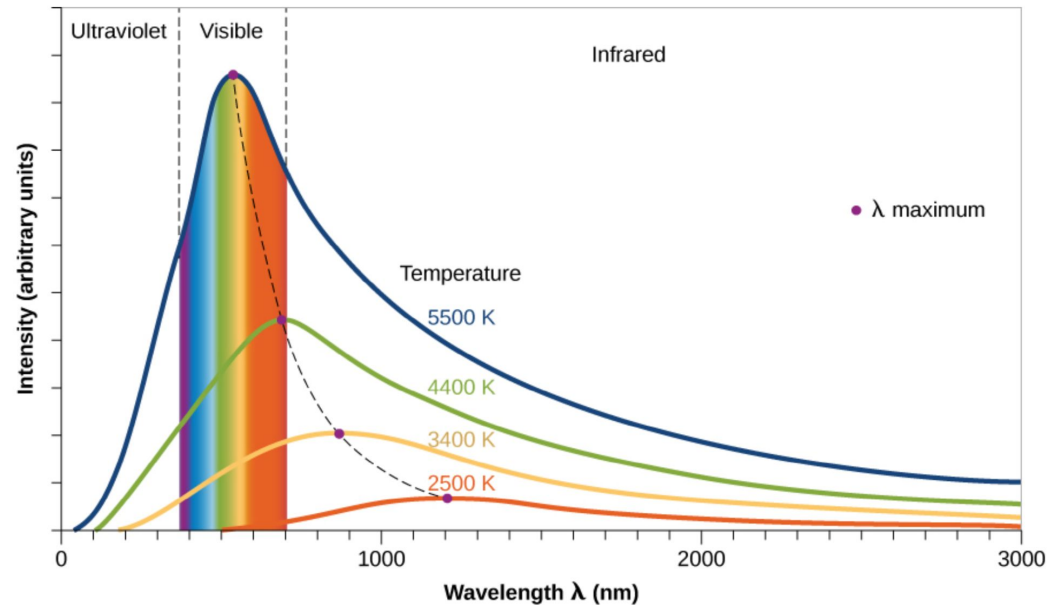
X-Ray Sky. This is a map of the sky tuned to certain types of X-rays (seen from above Earth's atmosphere). The map tilts the sky so that the disk of our Milky Way Galaxy runs across its center. It was constructed and artificially colored from data gathered by the European ROSAT satellite. Each color (red, yellow, and blue) shows X-rays of different frequencies or energies. For example, red outlines the glow from a hot local bubble of gas all around us, blown by one or more exploding stars in our cosmic vicinity. Yellow and blue show more distant sources of X-rays, such as remnants of other exploded stars or the active center of our Galaxy (in the middle of the picture). (credit: modification of work by NASA)

Figure 5.8 Blackbody Radiation



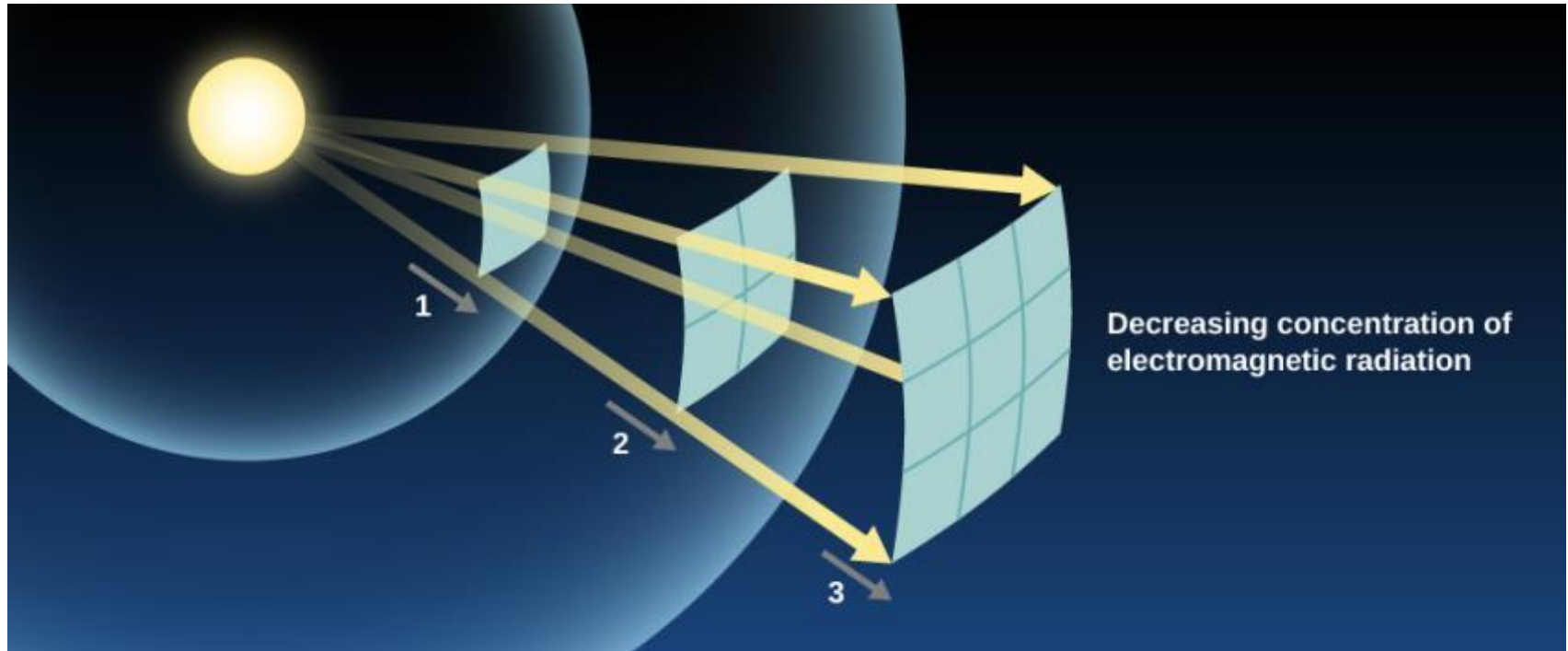
Radiation Laws Illustrated. This graph shows in arbitrary units how many photons are given off at each wavelength for objects at four different temperatures. The wavelengths corresponding to visible light are shown by the colored bands. Note that at hotter temperatures, more energy (in the form of photons) 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)

Figure 5.8 Blackbody Radiation



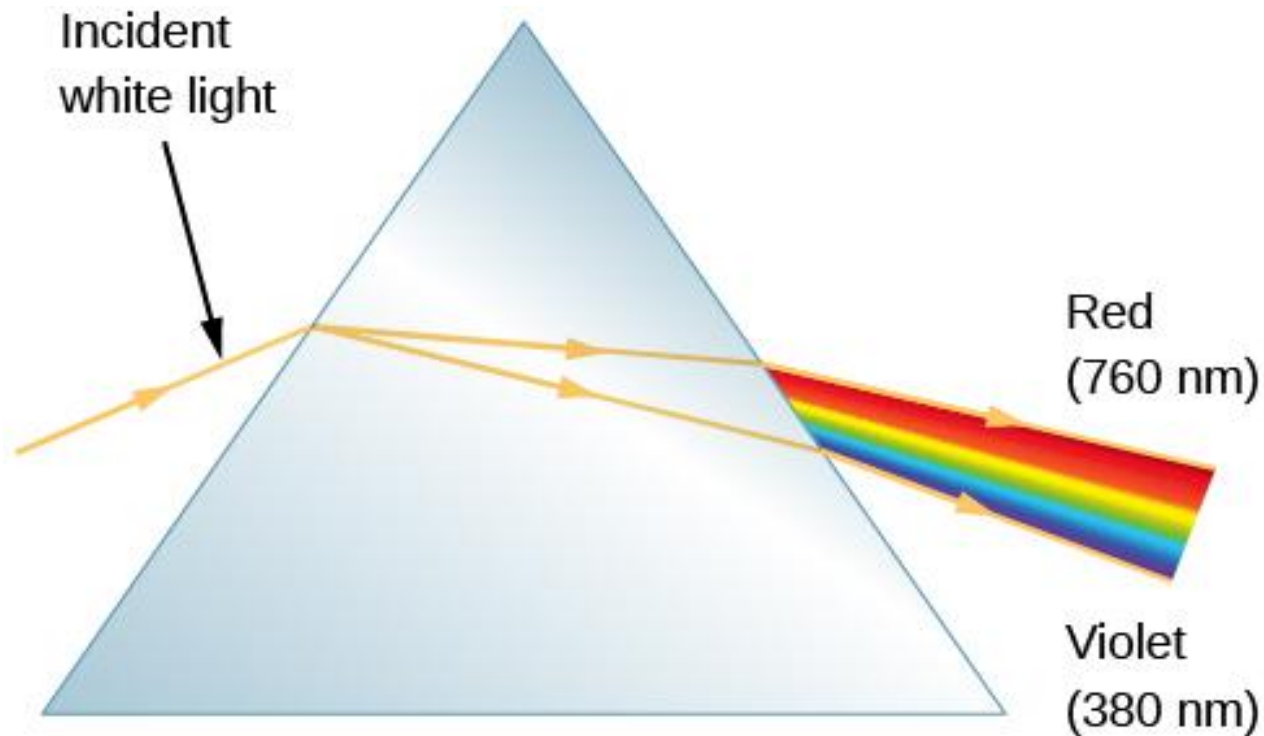
1. Emit a broad range, or spectrum, of energies and wavelengths due to slow and fast vibrations and collisions.
2. Hot stars give off more energy than cooler stars
3. Becomes a rough sort of “thermometer” for measuring the temperatures of stars, the color of light that dominates a star’s appearance is a rough indicator of its temperature.

FIGURE 5.5



Inverse Square Law for Light. As light radiates away from its source, it spreads out in such a way that the energy per unit area (the amount of energy passing through one of the small squares) decreases as the square of the distance from its source.

FIGURE 5.9



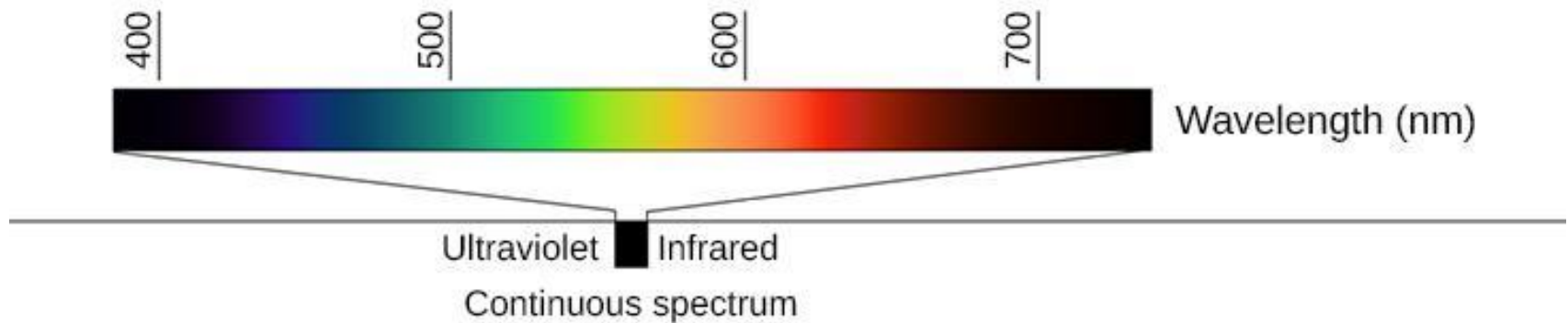
Action of a Prism (Dispersion of light). When we pass a beam of white sunlight through a prism, we see a rainbow-colored band of light that we call a continuous spectrum. This was the basis of Newton's first paper submitted to the Royal Society (30 YO).

FIGURE 5.13



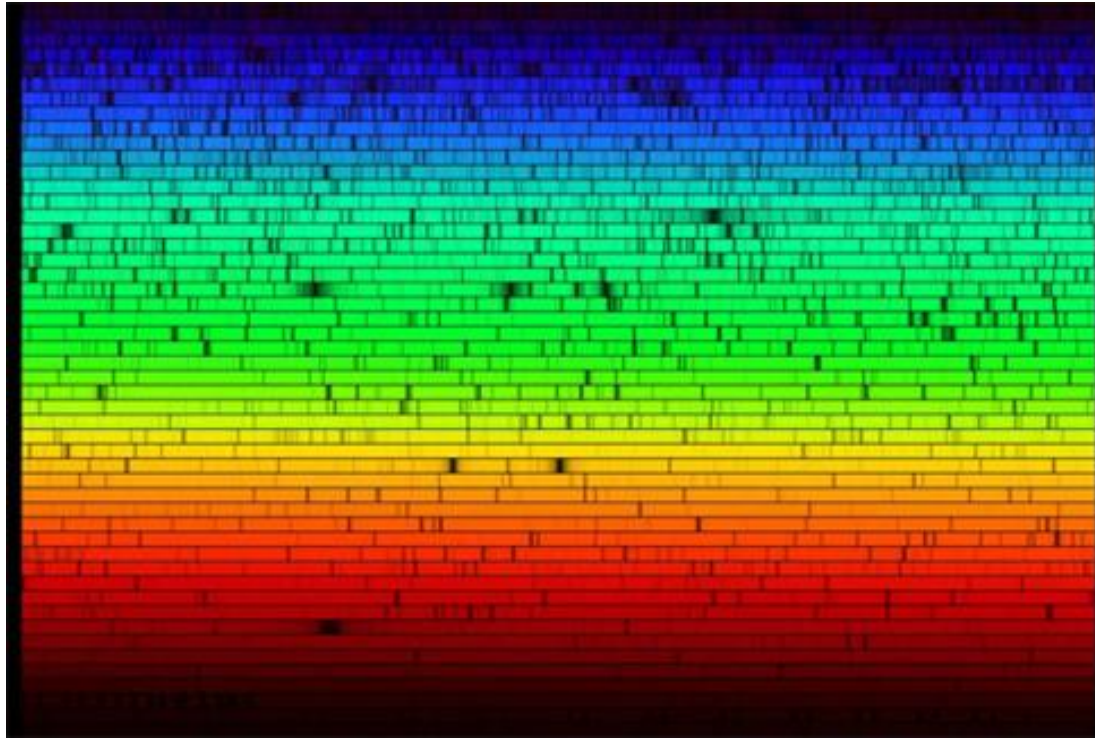
Rainbow Refraction. (a) This diagram shows how light from the Sun, which is located behind the observer, can be refracted by raindrops to produce (b) a rainbow. (c) Refraction separates white light into its component colors.

FIGURE 5.10



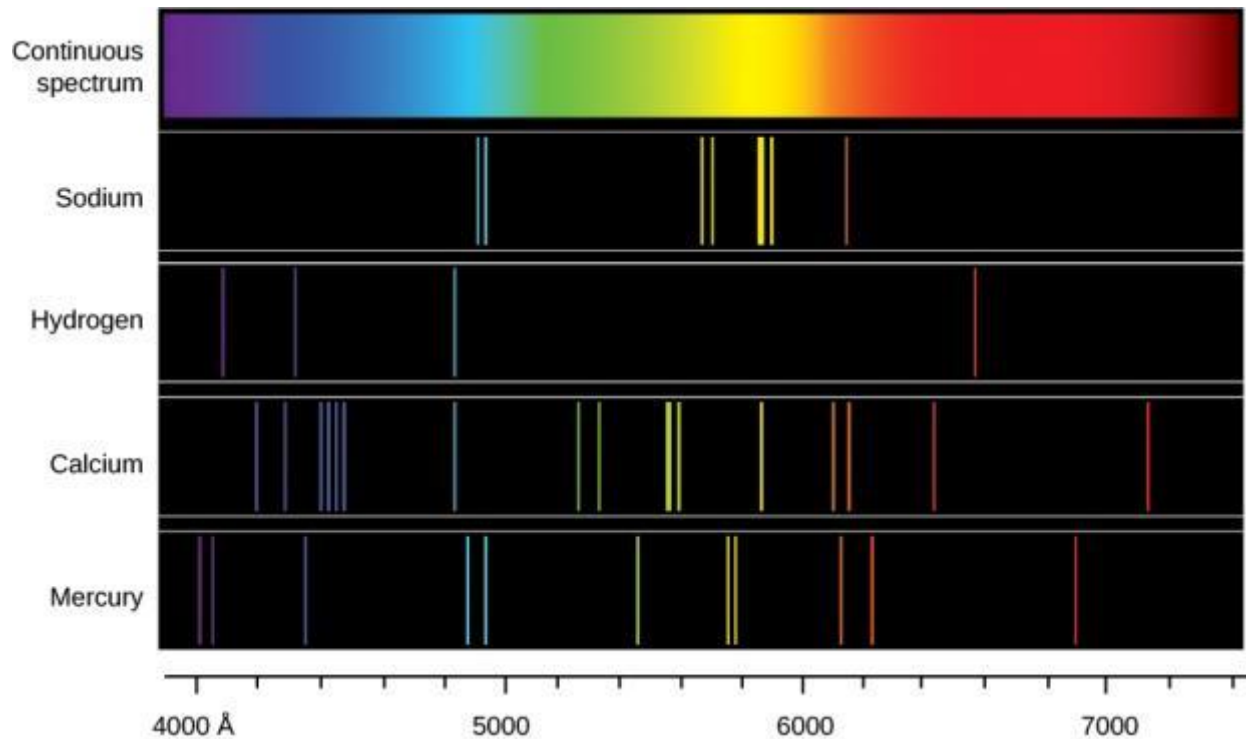
Continuous Spectrum. When white light passes through a prism, it is dispersed and forms a continuous spectrum of all the colors. Although it is hard to see in this printed version, in a well-dispersed spectrum, many subtle gradations in color are visible as your eye scans from one end (violet) to the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

FIGURE 5.11: Absorption Spectra



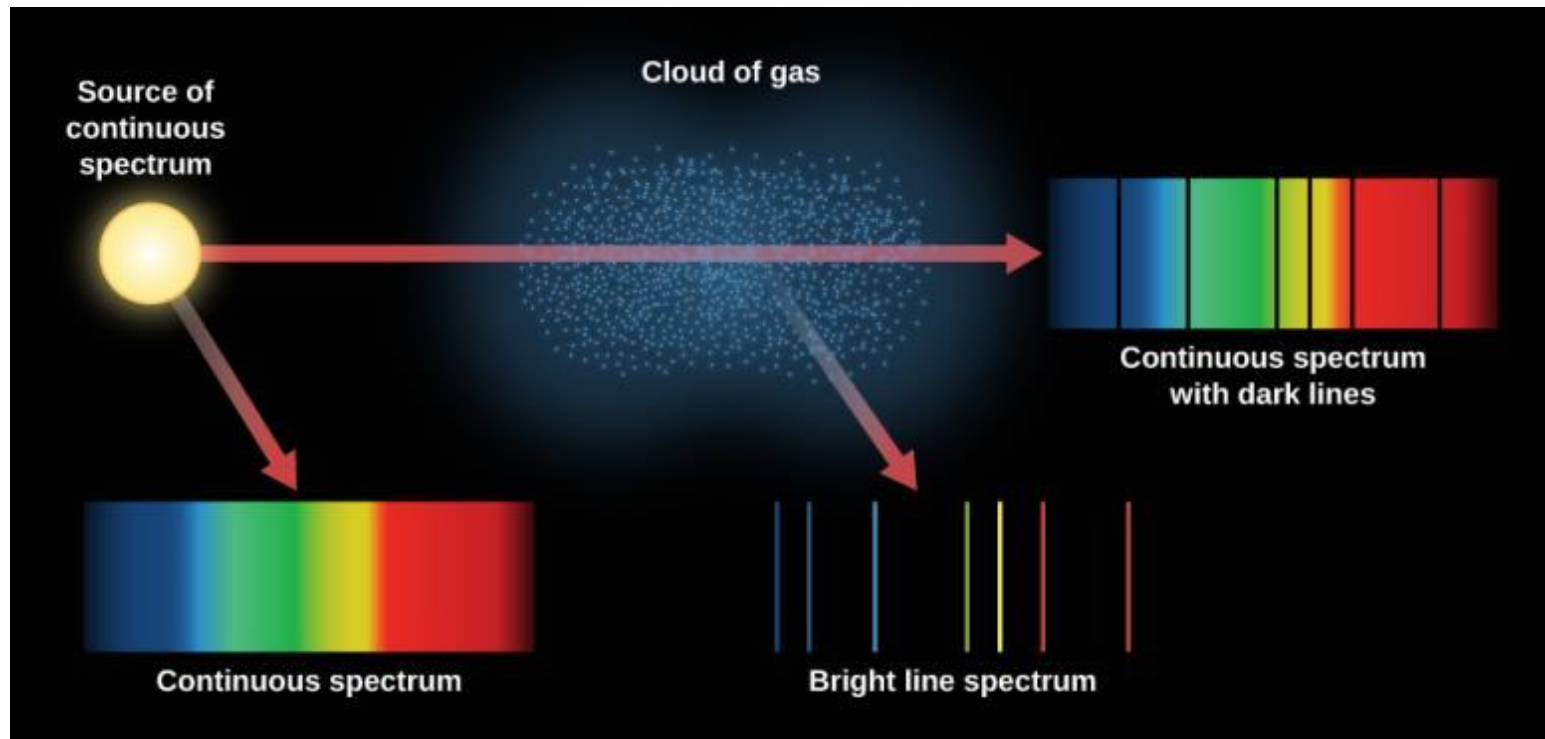
Visible Spectrum of the Sun. Our star's spectrum is crossed by dark lines produced by atoms in the solar atmosphere that absorb light at certain wavelengths. Absorption Spectra. (credit: modification of work by Nigel Sharp, NOAO/National Solar Observatory at Kitt Peak/AURA, and the National Science Foundation)

FIGURE 5.12: Emission Spectra



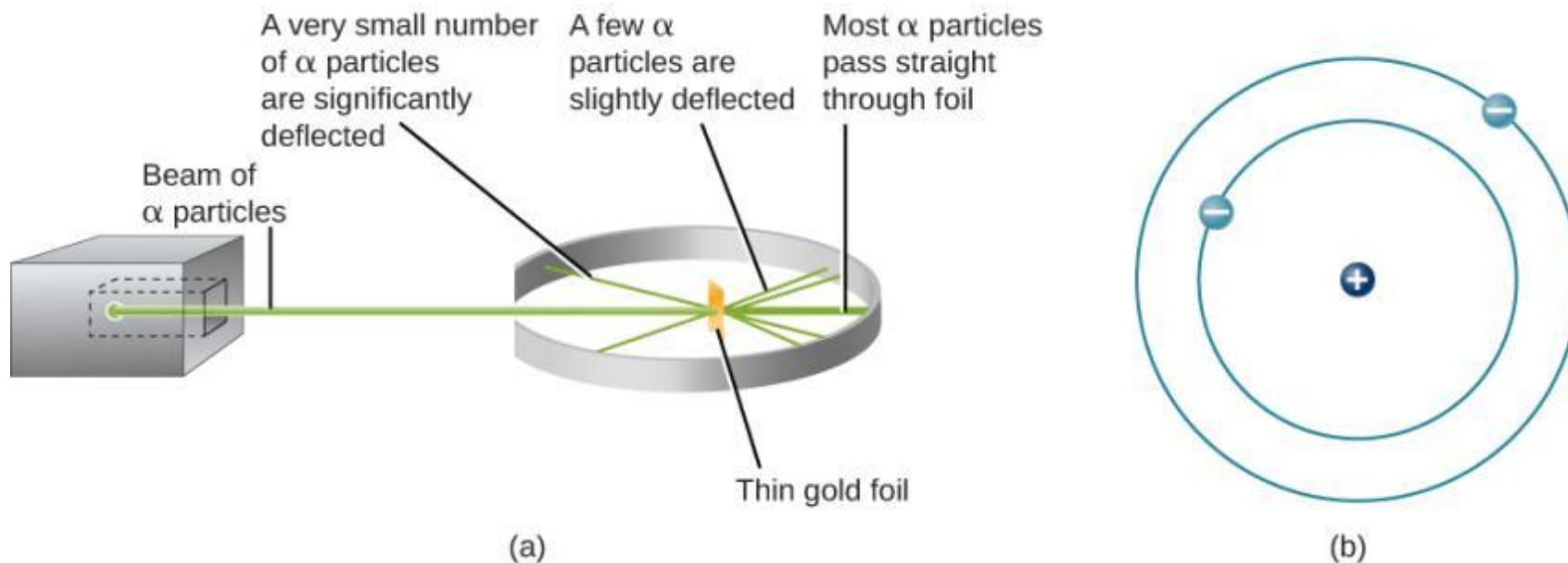
Continuous Spectrum and Line Spectra from Different Elements. Each type of glowing gas (each element) produces its own unique pattern of lines, so the composition of a gas can be identified by its spectrum. The spectra of sodium, hydrogen, calcium, and mercury gases are shown here. Emission Spectra.

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.

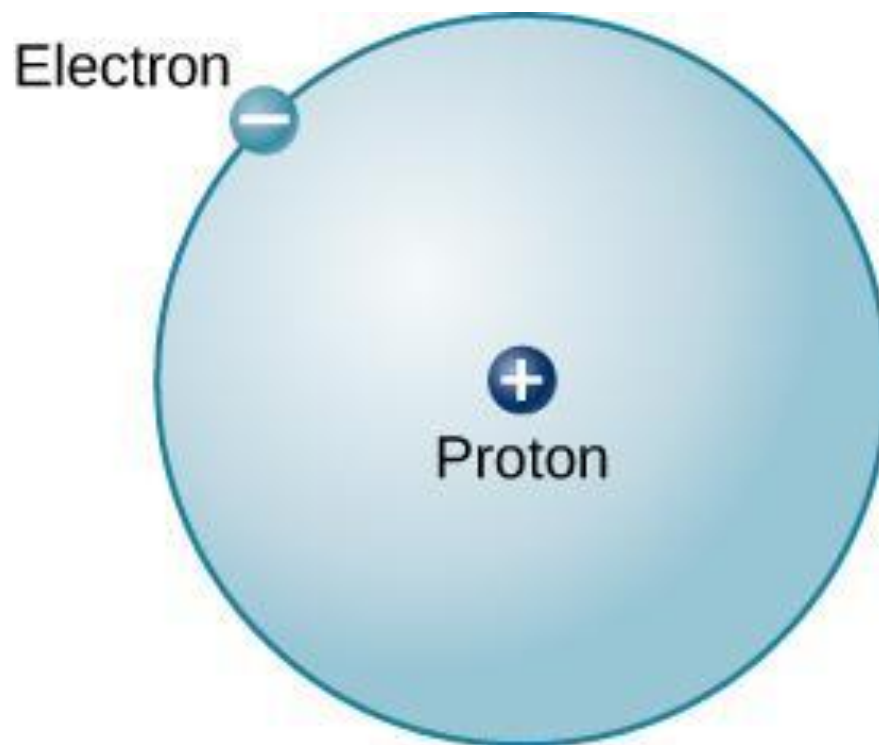
FIGURE 5.14



Rutherford's Experiment.

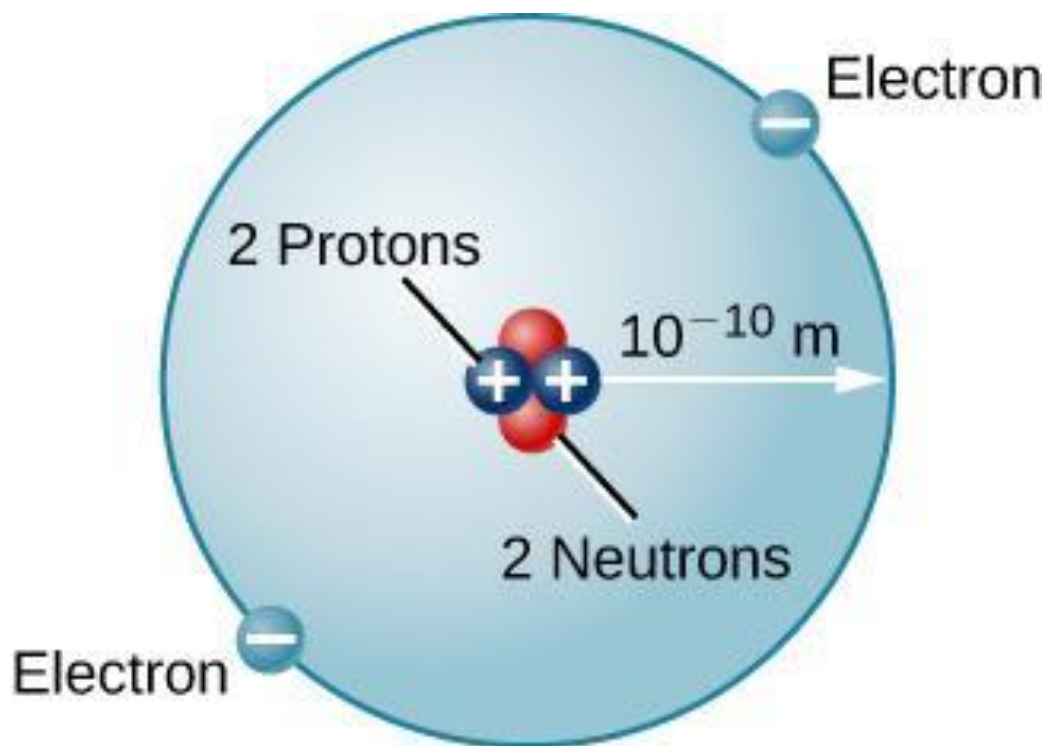
- (a) When Rutherford allowed α particles from a radioactive source to strike a target of gold foil, he found that, although most of them went straight through, some rebounded back in the direction from which they came.
- (b) From this experiment, he concluded that the atom must be constructed like a miniature solar system, with the positive charge concentrated in the nucleus and the negative charge orbiting in the large volume around the nucleus. Note that this drawing is not to scale; the electron orbits are much larger relative to the size of the nucleus.

FIGURE 5.15



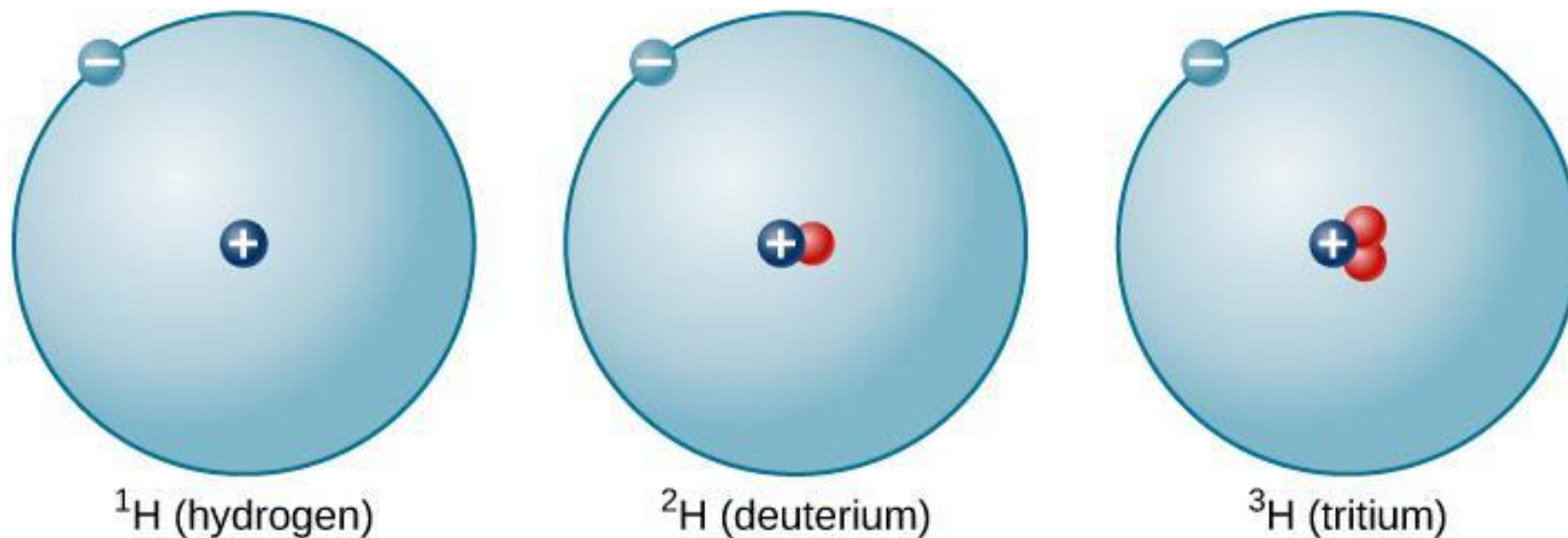
Hydrogen Atom. This is a schematic diagram of a hydrogen atom in its lowest energy state, also called the ground state. The proton and electron have equal but opposite charges, which exert an electromagnetic force that binds the hydrogen atom together. In the illustration, the size of the particles is 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 5.16



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 5.17



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 5.18



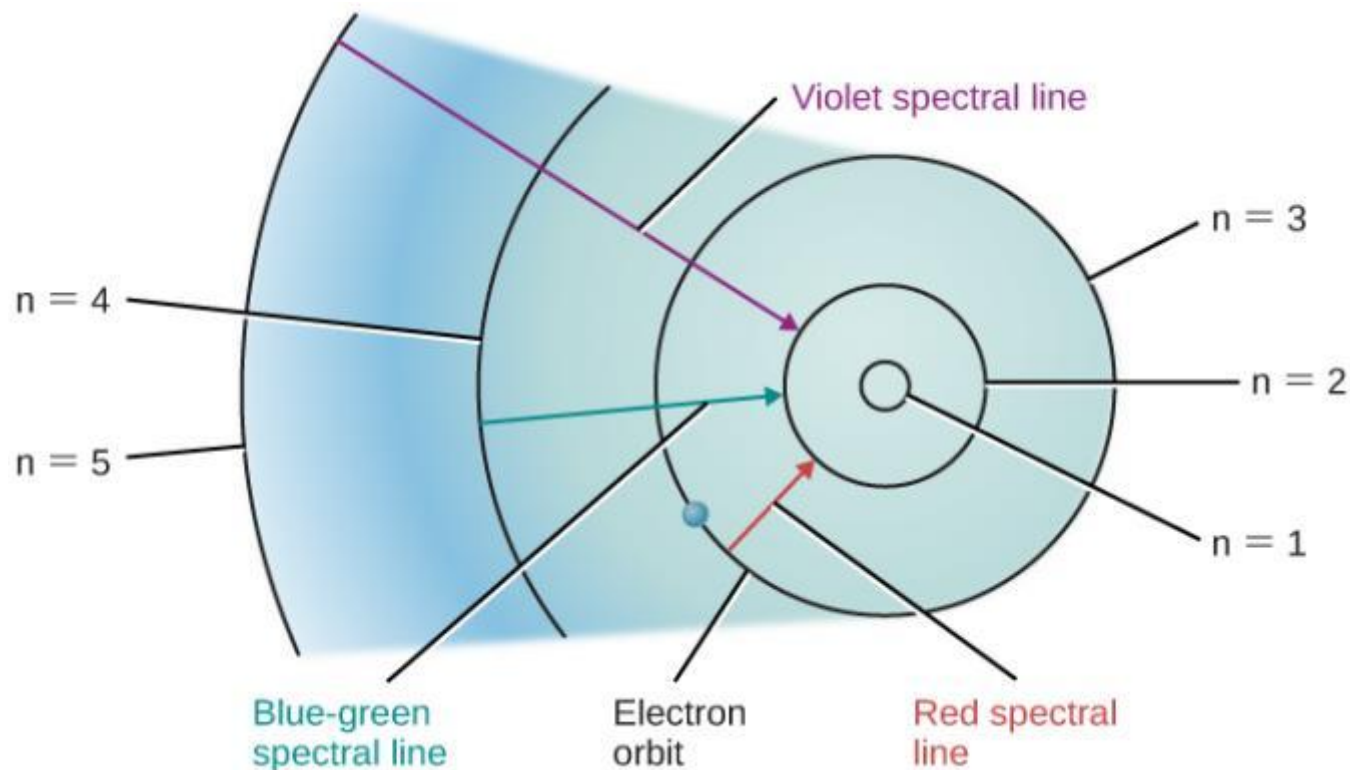
(a)



(b)

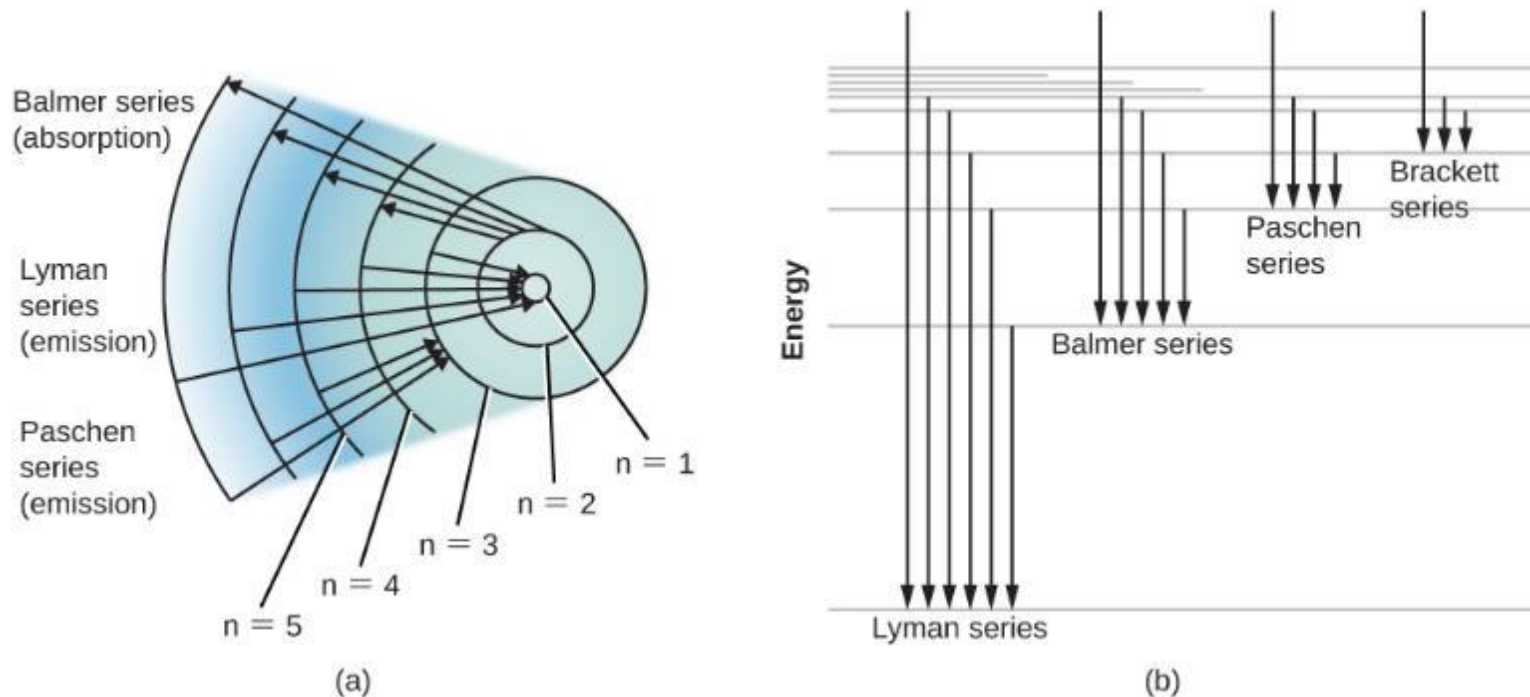
Niels Bohr (1885–1962) and Max Planck (1858–1947). (a) Bohr, shown at his desk in this 1935 photograph, and (b) Planck helped us understand the energy behavior of photons.

FIGURE 5.19



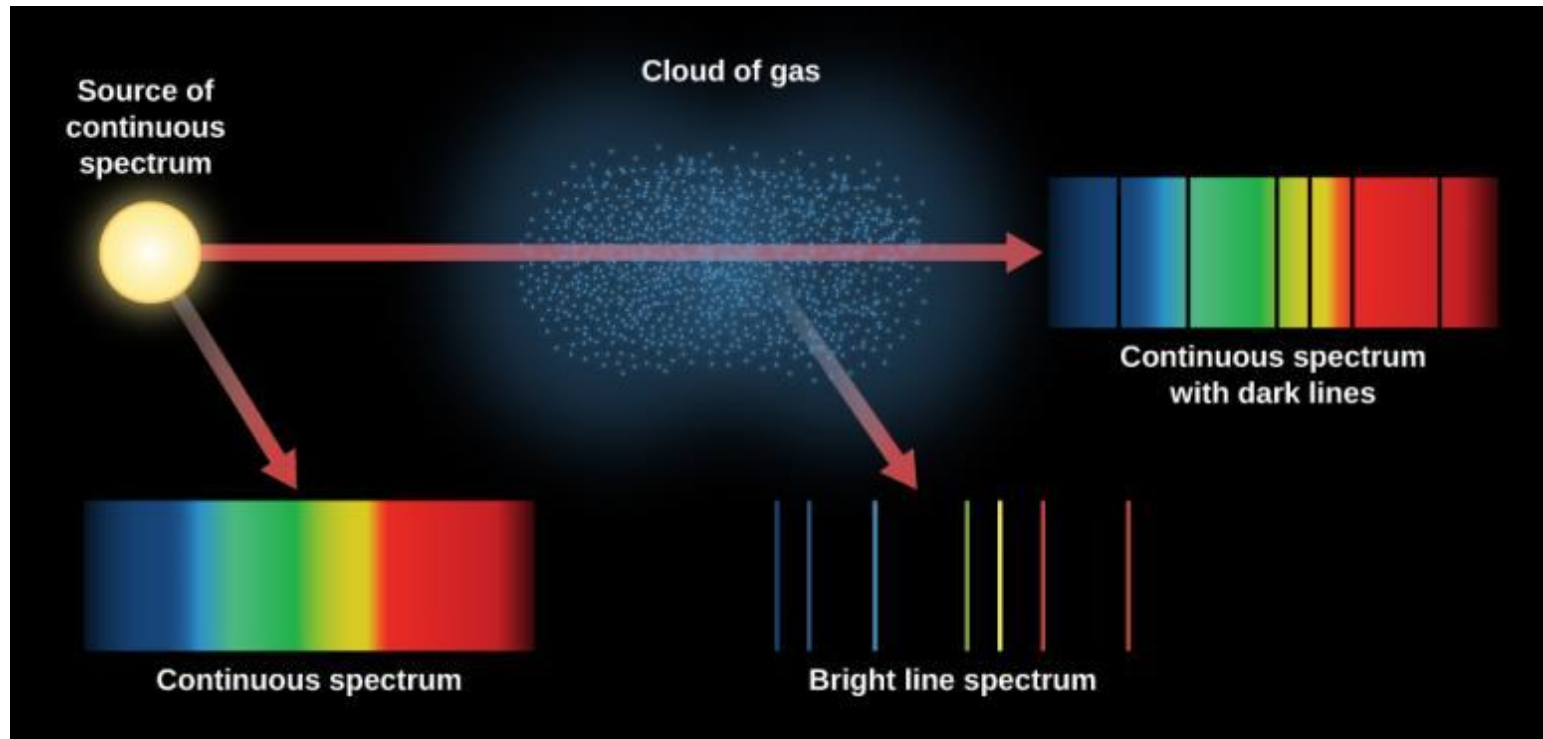
Bohr Model for Hydrogen. In this simplified model of a hydrogen atom, the concentric circles shown represent permitted orbits or energy levels. An electron in a hydrogen atom can only exist in one of these energy levels (or states). The closer the electron is to the nucleus, the more tightly bound the 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. (In this idealized diagram, the energy levels are shown equally spaced; in real life, they are not.) (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.