###### **Chapter 4** Name\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

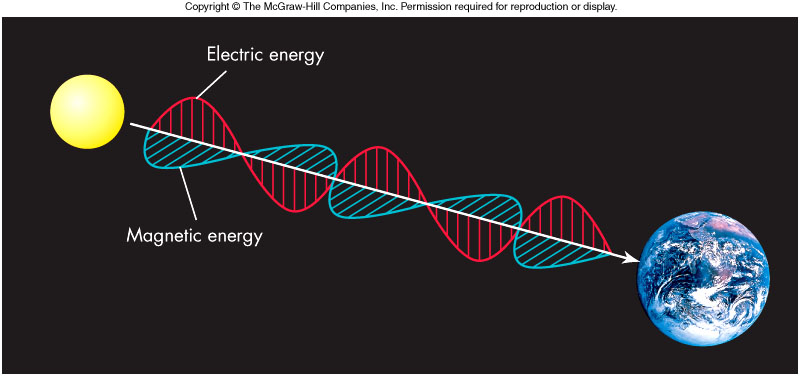
###### **Light – the Astronomer’s Tool**

* Due to the vast distances, with few exceptions, direct measurements of astronomical bodies are not possible
* We study remote bodies indirectly by \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Understanding the properties of light is therefore essential
* Care must be given to distinguish light signatures that belong to the distant body from signatures that do not (e.g., our atmosphere may distort distant light signals)

**Properties of Light**

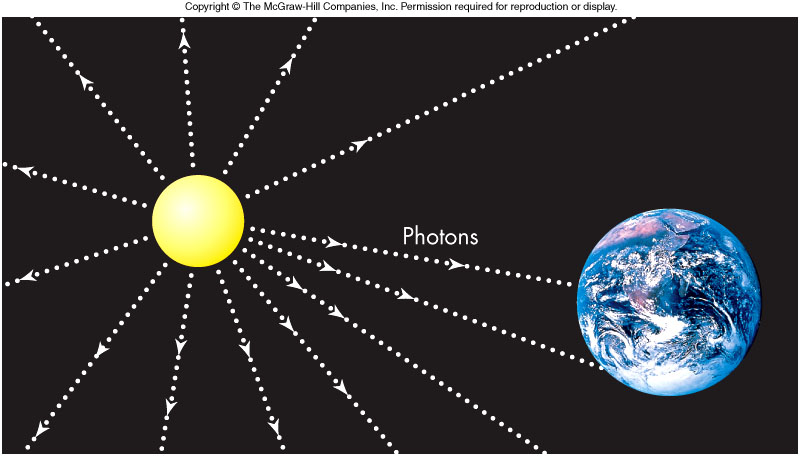
* + *Light* is \_\_\_\_\_\_\_\_\_\_\_\_\_\_it does not require a \_\_\_\_\_\_\_\_\_\_\_\_ for travel (unlike sound!)
  + Light travels at \_\_\_\_\_\_\_\_\_\_\_\_\_ in a vacuum (fast enough to circle the Earth 7.5 times in one second)
  + Speed of light *\_\_\_\_\_\_\_\_\_\_\_* is constant and is denoted by the letter \_\_
  + However, the speed of light is reduced as it passes through transparent materials
    - The speed of light in transparent materials is dependent on \_\_\_\_\_\_\_\_\_\_\_\_\_
    - Fundamental reason telescopes work the way they do!

**Sometimes light can be described as a wave…**



* + The wave travels as a result of a fundamental relationship between \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
  + A \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ creates an \_\_\_\_\_\_\_\_\_\_\_\_\_\_ and a \_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ creates a \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

…and sometimes it can be described as a particle!

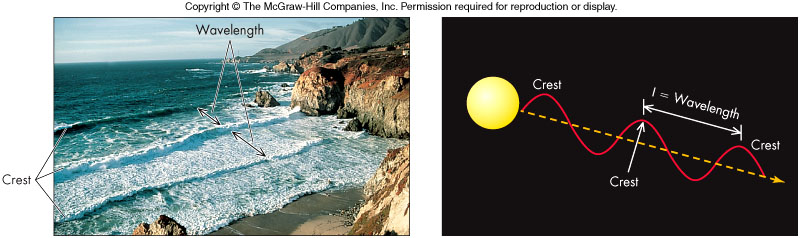


* + Light thought of as a stream of particles called ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_***
  + Each photon particle carries energy, depending on its ***\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***

**So which model do we use?**

* + Well, it depends!
    - In a vacuum, \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, but behave like \_\_\_\_\_\_\_\_\_\_\_\_\_\_
    - \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ particles also act as waves
    - *\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_* All particles of nature behave as both a wave and a particle
    - Which property of light manifests itself depends on the situation
    - We concentrate on the wave picture henceforth

**Light and Color**

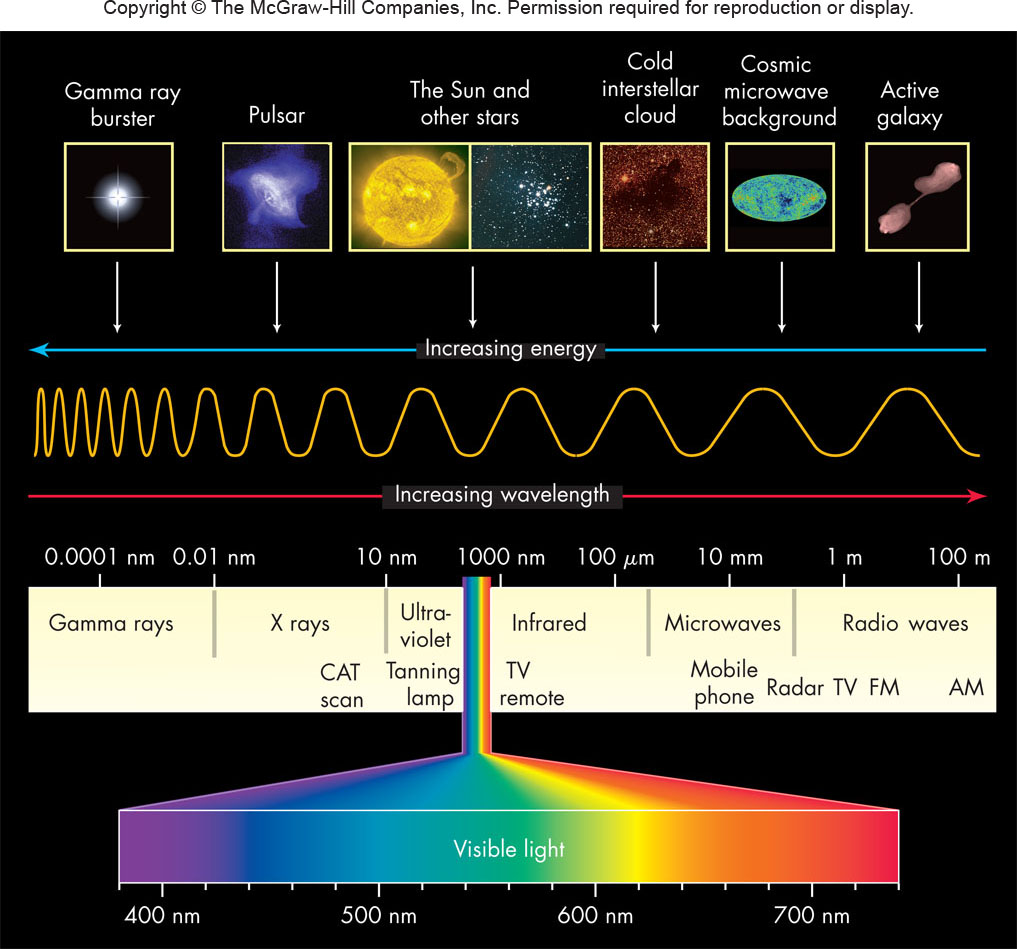


* Colors to which the human eye is sensitive is referred to as the ***\_\_\_\_\_\_\_\_***

***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***

* In the wave theory, color is determined by the light’s ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_*** (symbolized as \_\_\_\_\_\_\_)
  + The***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*** is the convenient unit
  + \_\_\_\_\_\_\_\_= 700 nm (\_\_\_\_\_\_\_\_\_\_\_ wavelength), \_\_\_\_\_\_\_\_ = 400 nm (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ wavelength)

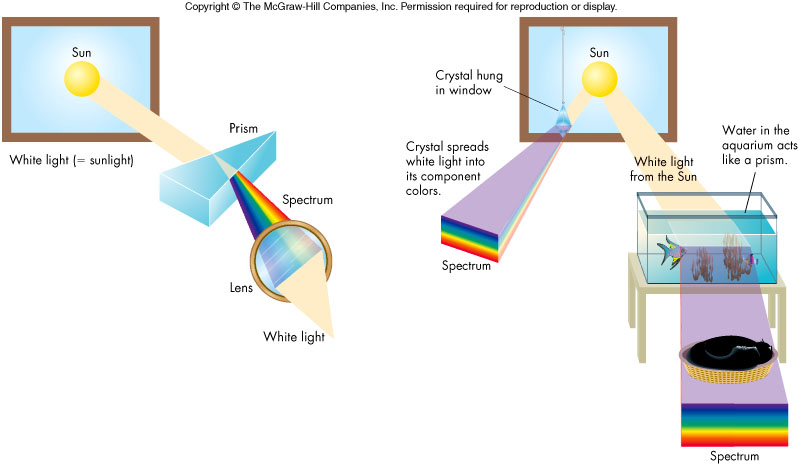
**The Visible Spectrum**



**Frequency**

* Sometimes it is more convenient to talk about light’s frequency
  + ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***\_\_ is the number of wave crests that pass a given point in 1 second (measured in \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_)
  + Important relation: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
  + \_\_\_\_\_\_\_\_\_\_\_wavelength = \_\_\_\_\_\_\_\_\_\_frequency
  + \_\_\_\_\_\_\_wavelength = \_\_\_\_\_\_\_\_\_\_\_\_\_\_ frequency

**White light – a mixture of all colors**



A \_\_\_\_\_\_\_\_\_ demonstrates that \_\_\_\_\_\_\_\_\_light is a \_\_\_\_\_\_\_\_\_\_\_\_\_ of wavelengths by its creation of a spectrum

Additionally, one can \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ a spectrum of colors and obtain white light

**The Electromagnetic Spectrum**

* The***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*** is composed of **\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**
* Longest wavelengths are more than **\_\_\_\_\_\_\_\_\_\_**
* Shortest wavelengths are less than **\_\_\_\_\_\_\_\_\_\_**
* Various instruments used to explore the various regions of the spectrum

**Infrared Radiation**

* Sir William Herschel (around 1800) showed \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ related to visible light
* He measured an elevated temperature just off the red end of a solar spectrum – ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***

**Ultraviolet Light**

* J. Ritter in 1801 noticed silver chloride blackened when exposed to “light” just beyond the \_\_\_\_\_\_\_\_\_\_\_\_\_\_ of the visible spectrum
* Mostly absorbed by the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.
* Responsible for suntans (and burns!)

**Radio Waves**

* Predicted by \_\_\_\_\_\_\_\_\_\_\_in mid-1800s, Hertz produced ***radio waves*** in 1888
* Jansky discovered radio waves from cosmic sources in the 1930s, the birth of radio astronomy
* Radio waves used to study a wide range of astronomical processes
* Radio waves also used for communication, microwave ovens, and search for extraterrestrials

**X-Rays**

* + Roentgen discovered X rays in\_\_\_\_\_\_\_\_\_\_\_\_\_\_
  + First detected beyond the Earth in the Sun in late 1940s
  + Used by doctors to scan \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
  + Used by astronomers to detect \_\_\_\_\_\_\_\_\_\_\_\_ and \_\_\_\_\_\_\_\_\_\_\_\_\_ in distant galaxies

**Energy Carried by Electromagnetic Radiation**

* + Each photon of wavelength\_\_\_\_ carries an energy E given by:

where h is Planck’s constant

* + Notice that a photon of \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ radiation carries \_\_\_\_\_\_\_\_\_\_\_\_energy than a long wavelength photon

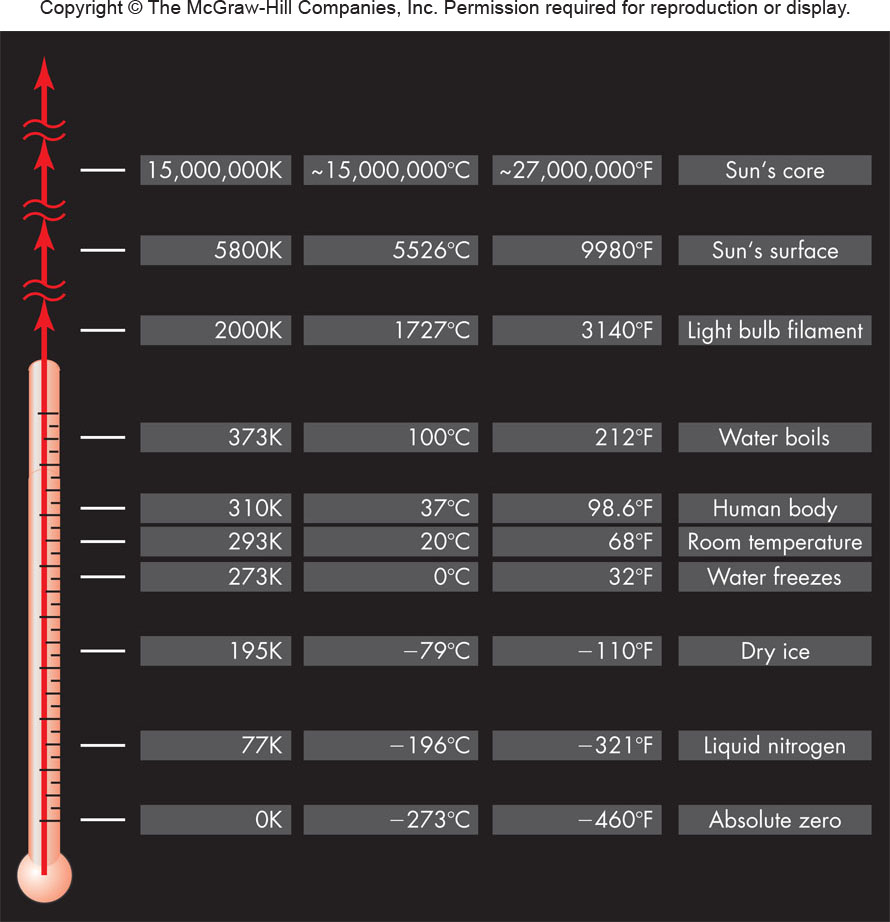
**Matter and Heat**

* The Nature of Matter and Heat
  + The ancient Greeks introduced the idea of the atom (Greek for “\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_”), which today has been modified to include a nucleus and a surrounding cloud of electrons
  + Heating (\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_) and the motion of atoms was an important topic in the 1700s and 1800s

**A New View of Temperature**

* The Kelvin Temperature Scale
  + An object’s temperature is directly related to its energy content and to the speed of molecular motion
  + As a body is cooled to zero Kelvin, molecular motion within it slows to a virtual halt and its energy approaches zero Þ no negative temperatures

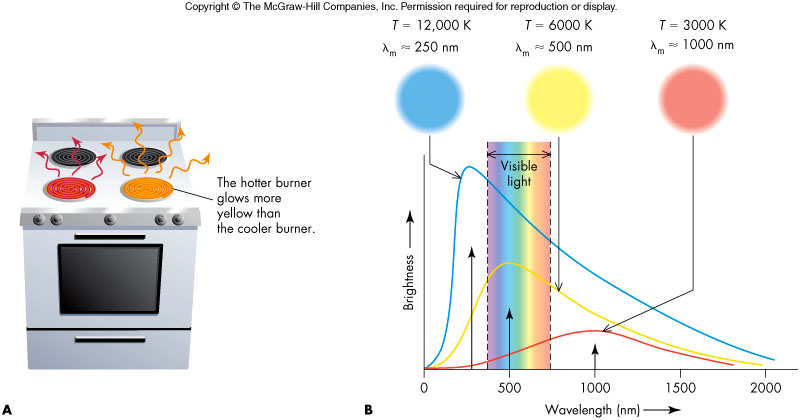
Fahrenheit and Celsius are two other temperature scales that are easily converted to Kelvin.



**Radiation and Temperature**

* Heated bodies generally radiate across the entire electromagnetic spectrum
* There is one particular wavelength**, \_\_\_\_\_\_,** at which the radiation is most intense and is given by [***Wien’s Law:***](http://www.youtube.com/watch?v=wZhpGFNl91s)

Where k is some constant and T is the temperature of the body

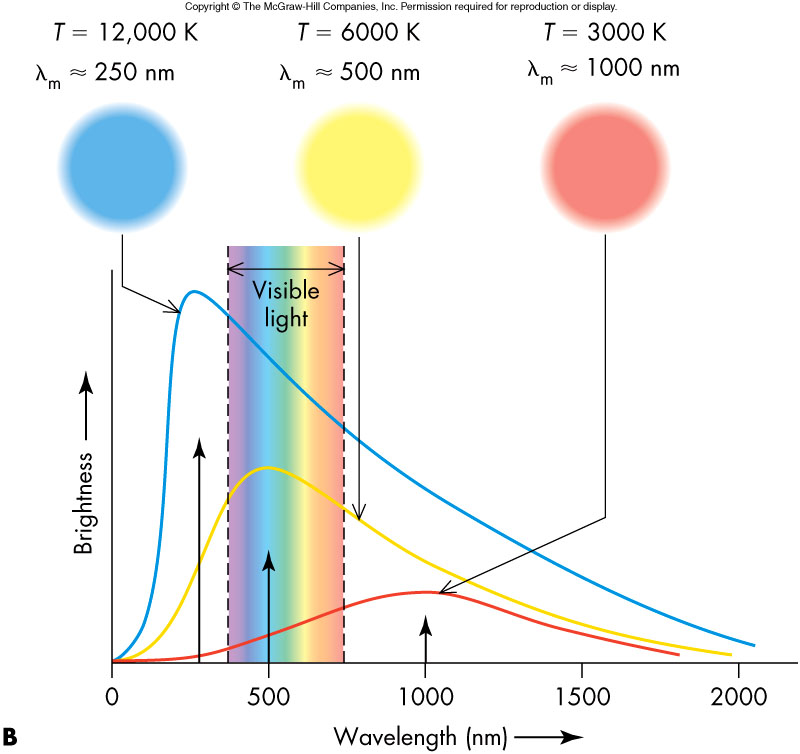


**Radiation and Temperature**

* + Note **\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_** bodies radiate more strongly at **\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**
  + As an object heats, it appears to change color from **\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_**
  + Measuring **\_\_\_\_\_\_\_\_** gives a body’s temperature
  + Careful: Reflected light does not give the temperature

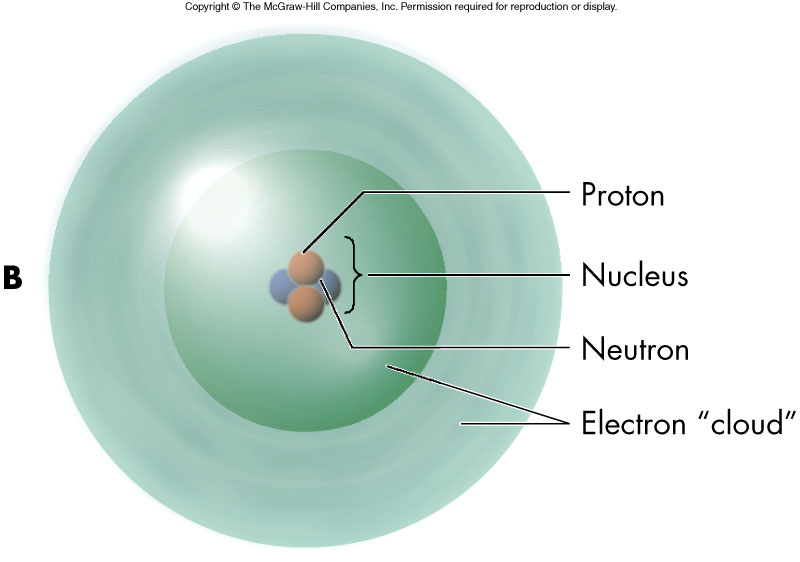
**Blackbodies and Wien’s Law**

* + A ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_*** is an object that absorbs all the radiation falling on it
  + Since such an object \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ any light, it appears black when cold, hence its name
  + As a blackbody is heated, it radiates more efficiently than any other kind of object
  + Blackbodies are excellent absorbers and emitters of radiation and follow Wien’s law
  + Very few real objects are perfect blackbodies, but many objects (e.g., the Sun and Earth) are close approximations
  + Gases, unless highly compressed, are not blackbodies and can only radiate in narrow wavelength ranges



The Structure of **Atoms**

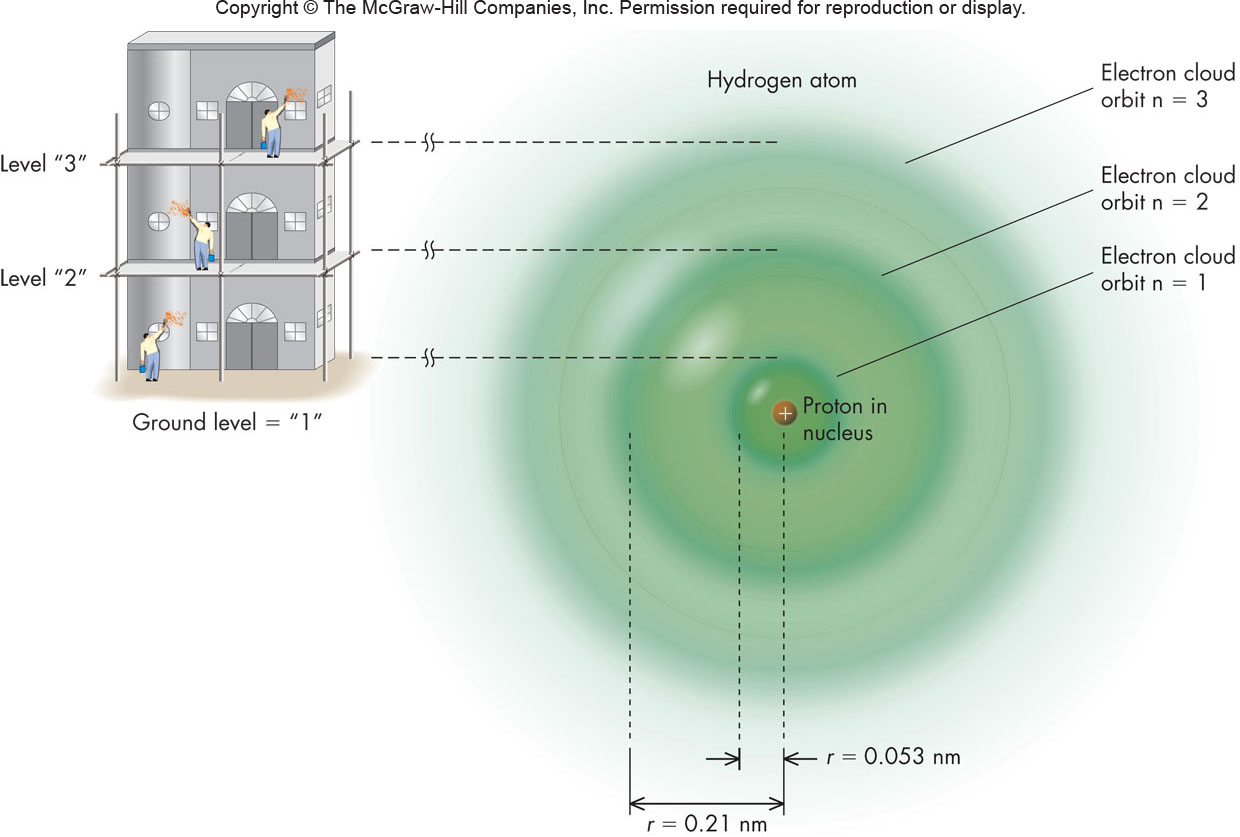
* Nucleus – Composed of densely packed \_\_\_\_\_\_\_\_\_\_ and positively charged \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* Cloud of negative \_\_\_\_\_\_\_\_\_\_\_\_\_\_ held in orbit around nucleus by positive charge of protons
* Typical atom size: 10-10 m (= \_\_\_\_\_\_ = 0.1 nm)



**The Chemical Elements**

* An ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***is a substance composed only of atoms that have the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of protons in their nucleus
* A neutral element will contain an \_\_\_\_\_\_\_\_\_\_\_\_\_ of \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_
* The chemical properties of an element are determined by the number of electrons

**Electron “Orbits”**

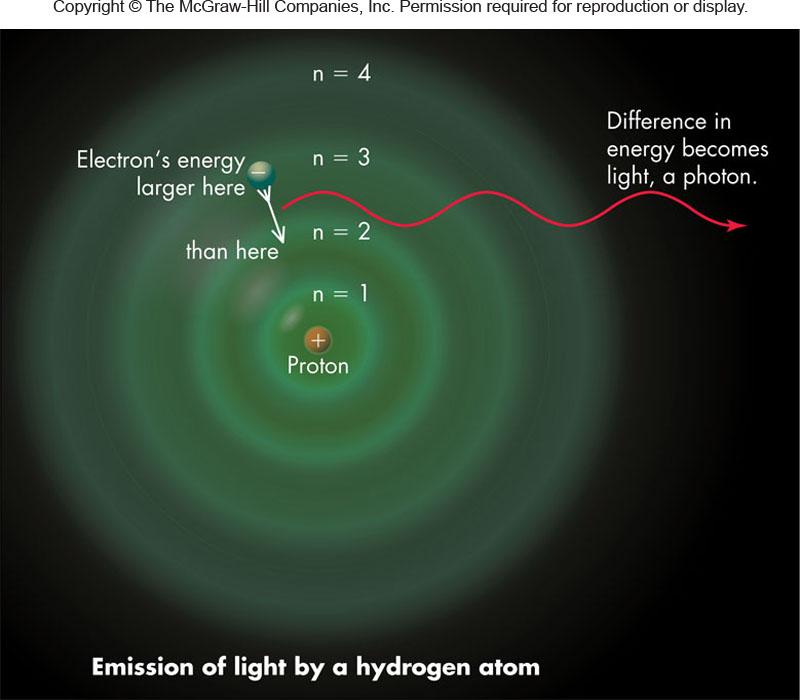


The electron orbits are ***\_\_\_\_\_\_\_\_\_\_\_\_\_,*** can only have \_\_\_\_\_\_\_\_\_\_\_\_values and nothing in between

Quantized orbits are the result of the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of matter

As electrons move from one orbit to another, they \_\_\_\_\_\_\_\_\_\_\_\_ their energy in discrete amounts

**Energy Change in an Atom**



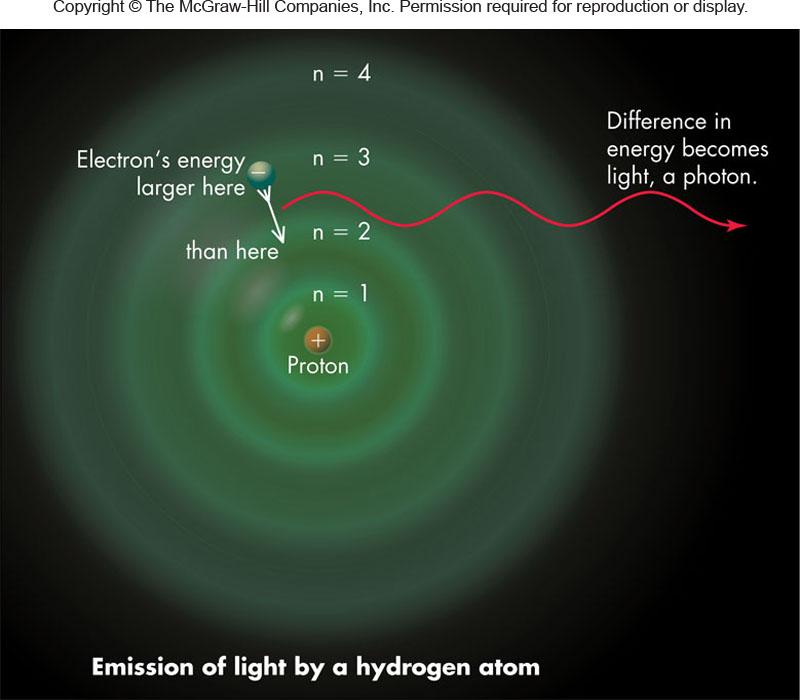
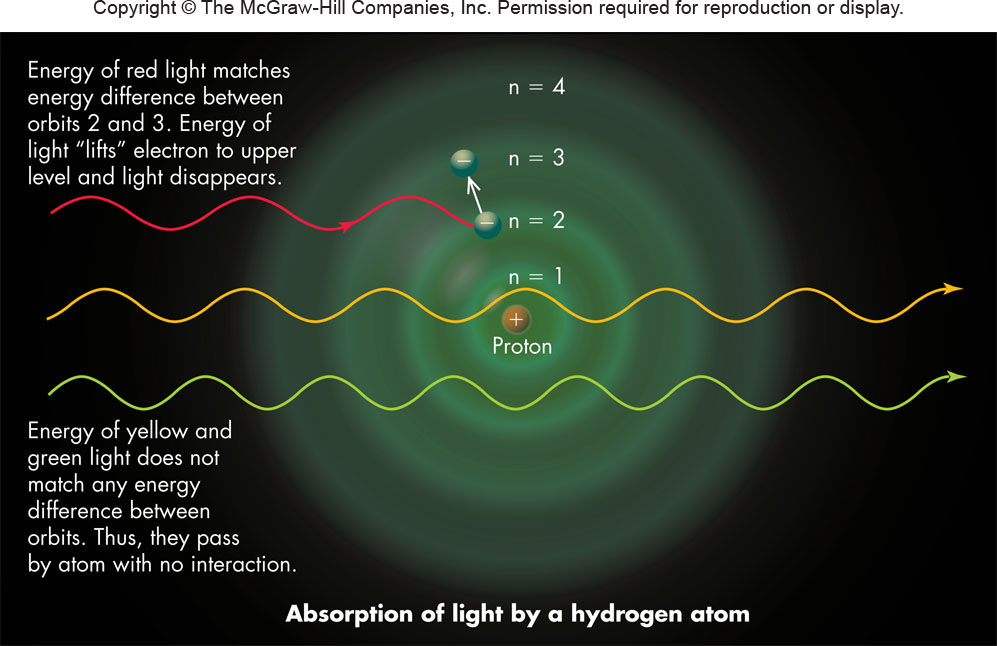
* An atom’s energy is increased if an electron moves to an outer orbit – the atom is said to be ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_.***
* An atom’s energy is decreased if an electron moves to an \_\_\_\_\_\_\_\_\_\_\_\_\_\_.

**Conservation of Energy**

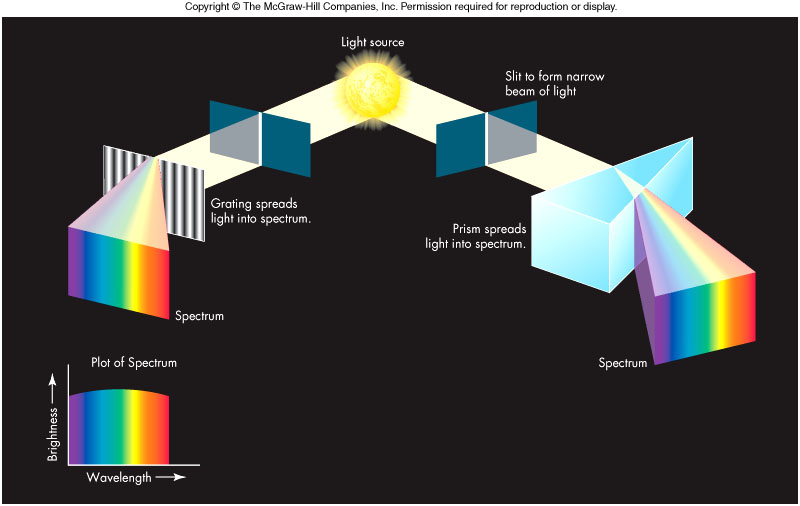
* The energy change of an atom must be compensated elsewhere – ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***
* ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_***and ***\_\_\_\_\_\_\_\_\_\_\_\_\_\_*** of EM radiation are two ways to preserve energy conservation
* In the photon picture, a photon is \_\_\_\_\_\_\_\_\_\_\_\_\_ as an electron moves to a higher orbit and a photon is\_\_\_\_\_\_\_\_\_\_\_\_\_\_as an electron moves to a lower orbit.

**Emission**

**Absorption**

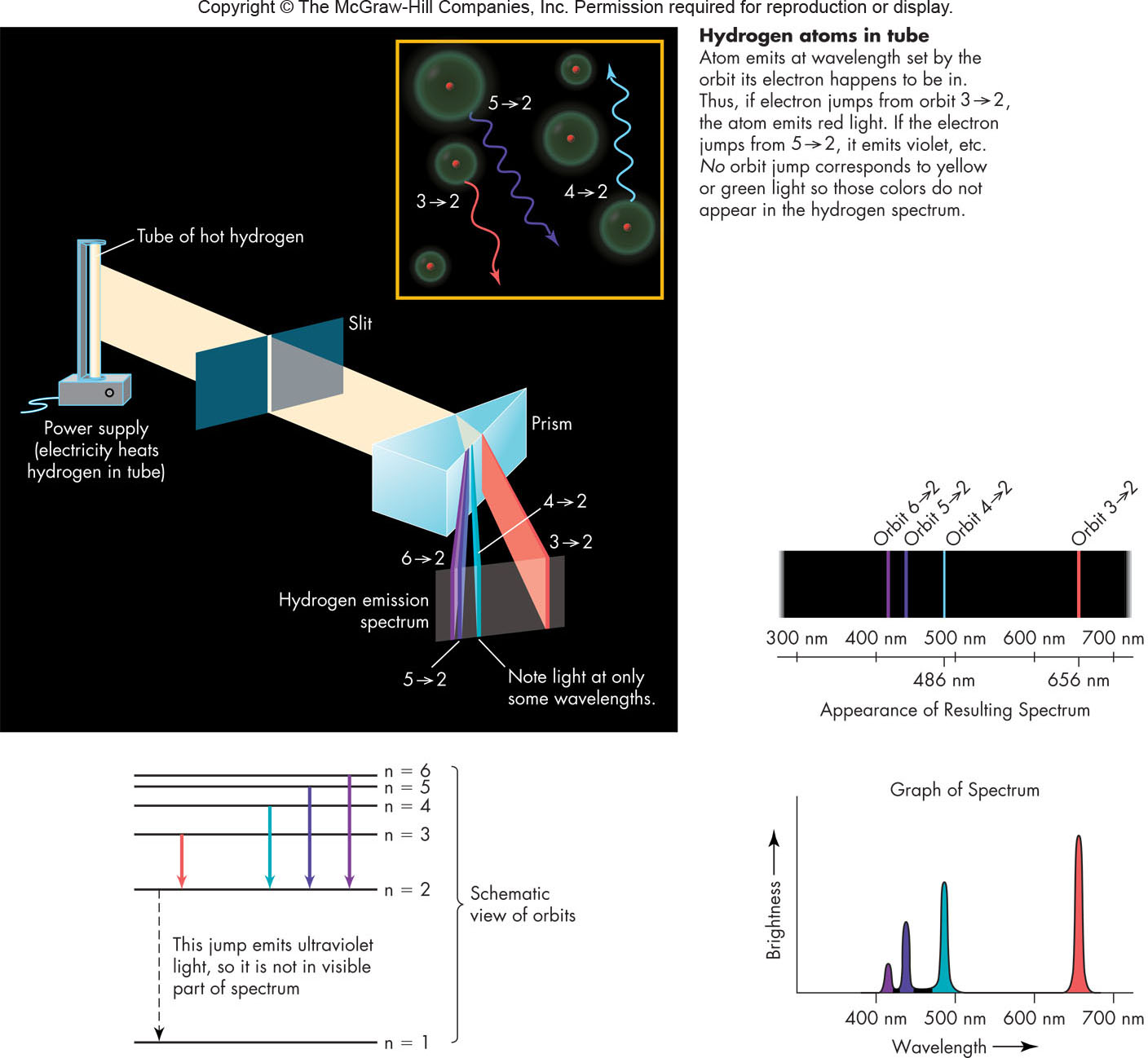


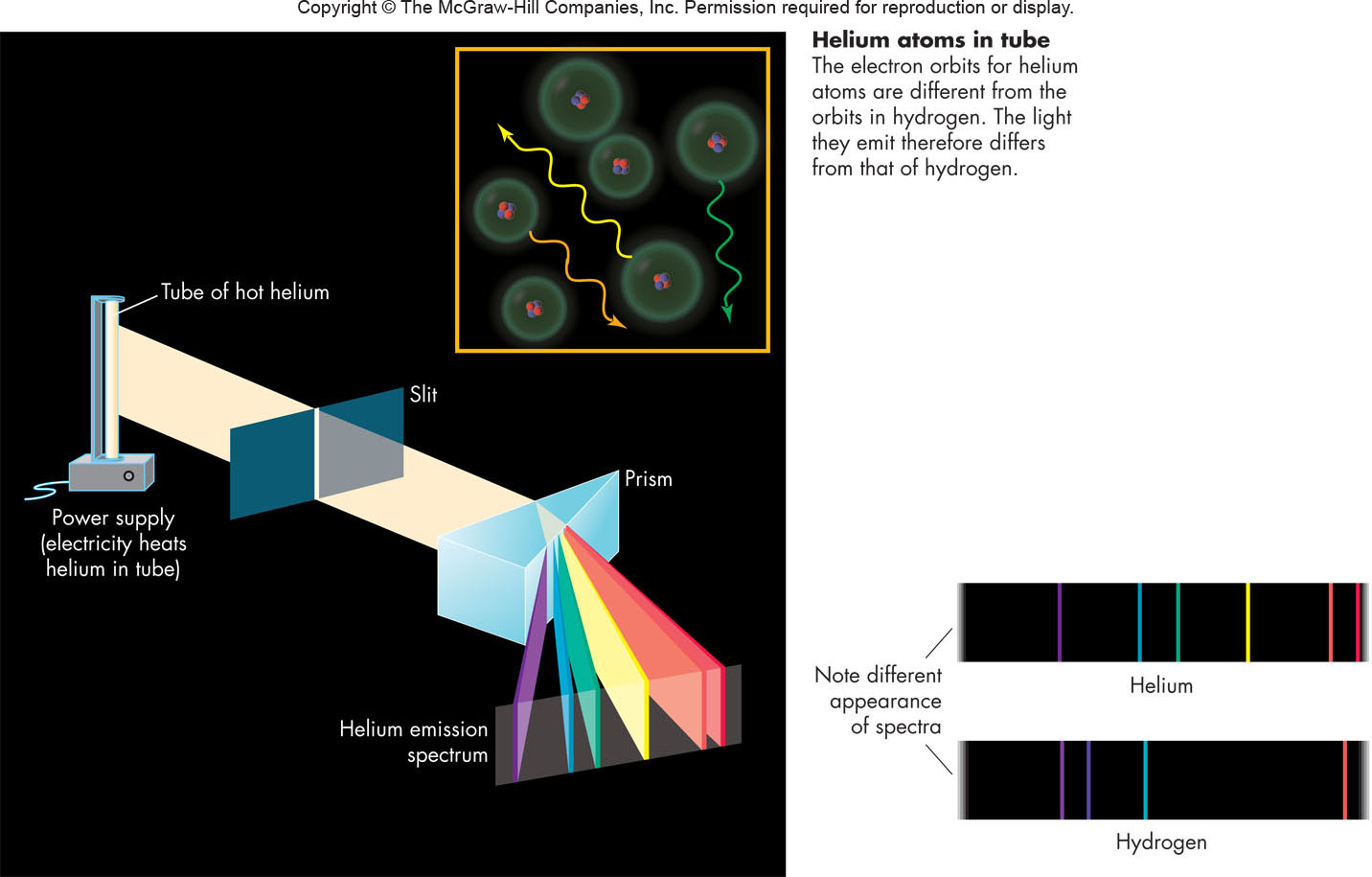
**Spectroscopy**



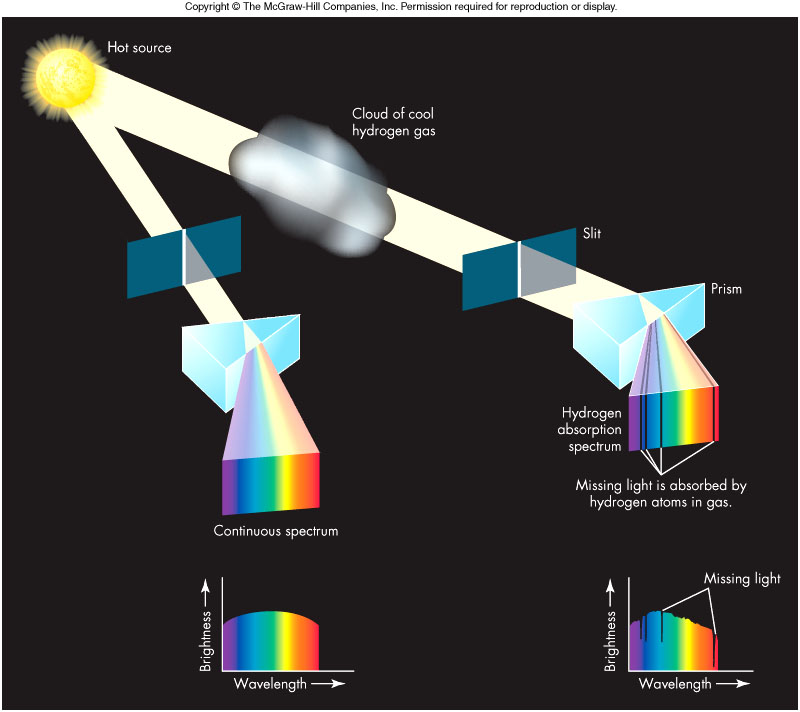
* ]
* Allows the determination of the \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ of an astronomical body
* In***\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_,***wecapture and analyze a spectrum
* Spectroscopy assumes that every \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ will have a unique spectral signature

**Emission Spectrum**

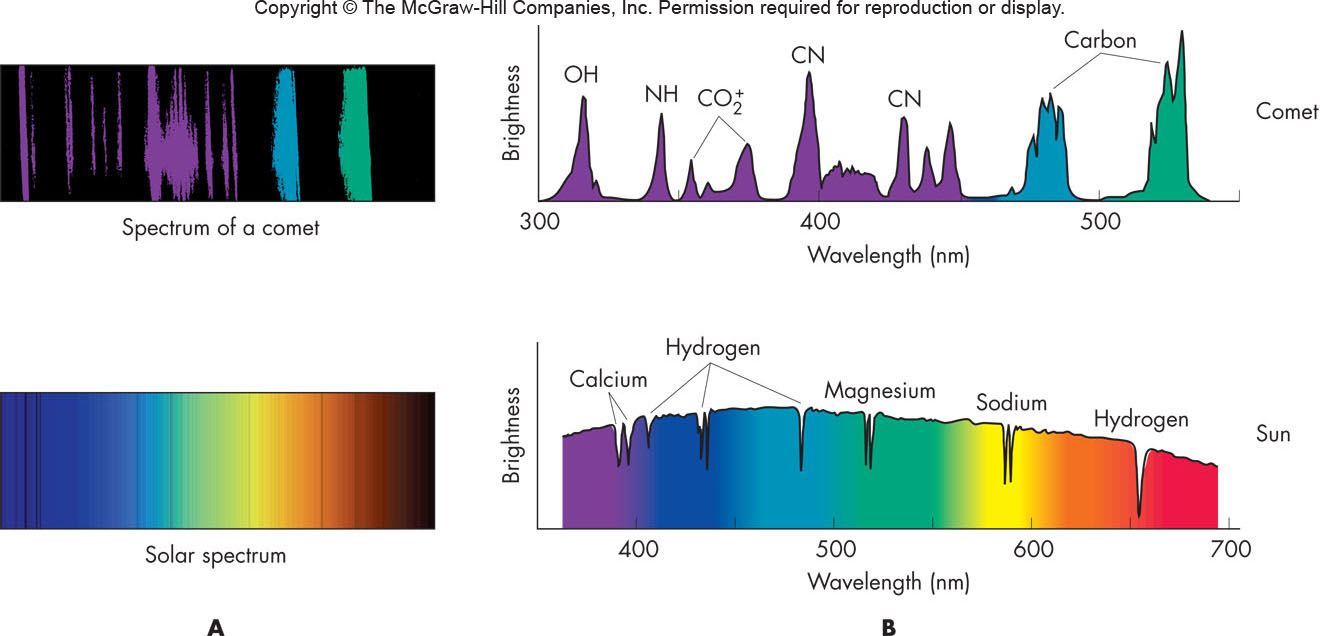




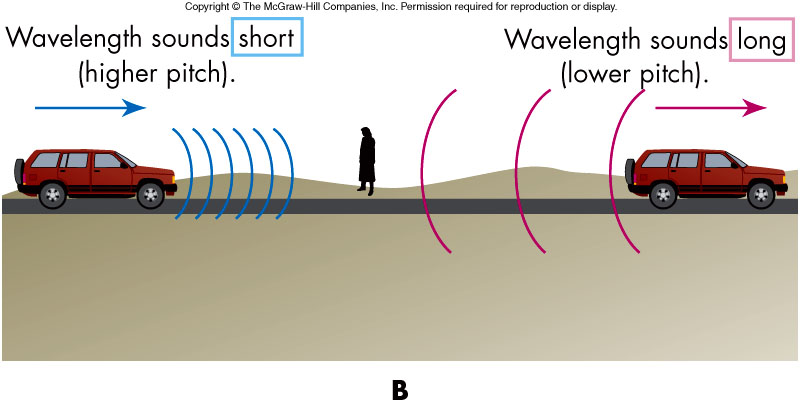
**Continuous and Absorption Spectra**



**Astronomical Spectra**



**Doppler Shift in Sound**

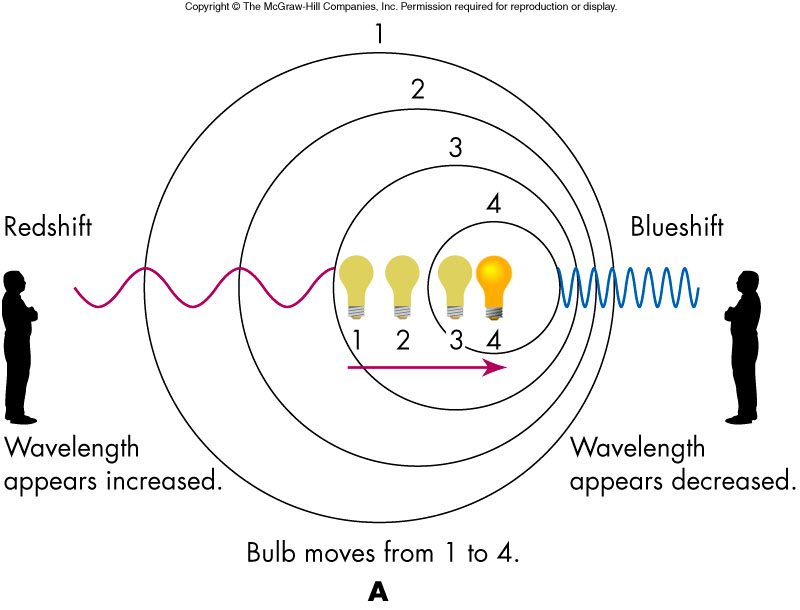


* If the source of sound is moving, the pitch \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_!

The shift in wavelength is given as

where \_\_\_ is the observed (shifted) wavelength,\_\_\_\_\_ is the emitted wavelength, v is the source non-relativistic \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_, and c is the speed of light

**Doppler Shift in Light**



If a source of light is set in motion relative to an observer, its spectral lines \_\_\_\_\_\_\_\_\_\_\_\_\_\_ to new wavelengths in a similar way

**Redshift and Blueshift**

* An observed increase in wavelength is called a \_\_\_\_\_\_\_\_\_\_, and a decrease in observed wavelength is called a \_\_\_\_\_\_\_\_\_\_\_ (regardless of whether or not the waves are visible)
* Doppler shift is used to determine an object’s velocity

**Absorption in the Atmosphere**

* Gases in the Earth’s atmosphere absorb electromagnetic radiation to the extent that most wavelengths from space do not reach the ground
* Visible light, most radio waves, and some infrared penetrate the atmosphere through *\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_****,*** wavelength regions of high transparency
* Lack of atmospheric windows at other wavelengths is the reason for astronomers placing telescopes in space.

