Astronomy

Semester 2

Weeks 5 - 6

Monday (February 2nd)

- See Week 4 Friday to make up for the closed school day

Tuesday (February 3rd)

- Shutdown Day

Wednesday / Thursday (February 4 – 5)

- Alien Project

Journal 4.3

- What are my post secondary educational plans?

- T: **(11) Science concepts. The student uses models to explain the formation, development, organization, and significance of solar system bodies. The student is expected to:**
- **11A** relate Newton's law of universal gravitation and Kepler's laws of planetary motion to the formation and motion of the planets and their satellites;
- **11B** explore and communicate the origins and significance of planets, planetary rings, satellites, asteroids, comets, Oort cloud, and Kuiper belt objects;
- O: I will be able to better understand the solar system and how life could exist on different celestial bodies
- D: by doing some research, analyzing the research, and building a model of an alien.
- A: solar system
- Y: How will you know that your alien would survive?

Friday (February 6th)

- C-Day

Monday / Tuesday (February 9 – 10)

- Begin Light Unit

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will be able to describe and calculate light as a wave
- D: by discussing light with my group, watching a video describing it, taking notes, and solving mathematical problems.
- A: light, frequency, speed of light, wavelength
- Y: What is the mathematical relationship between frequency and wavelength?

Light and Atoms

Light, the Astronomer's Tool

- Direct measurements of astronomical bodies are not possible.
- We study remote bodies indirectly by analyzing their light.
- 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 radiant energy: it does not require a medium for travel (unlike sound!).

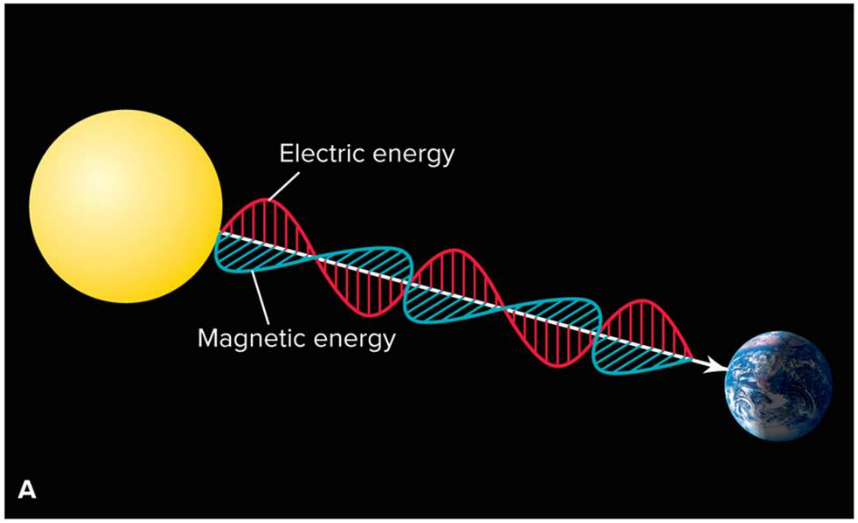
Light travels at 299,792.458 km/s in a vacuum (fast enough to circle Earth 7.5 times in one second). 3×10^8 m/s

Speed of light *in a vacuum* is constant and is denoted by the letter "c."

However, the speed of light is reduced as it passes through transparent materials.

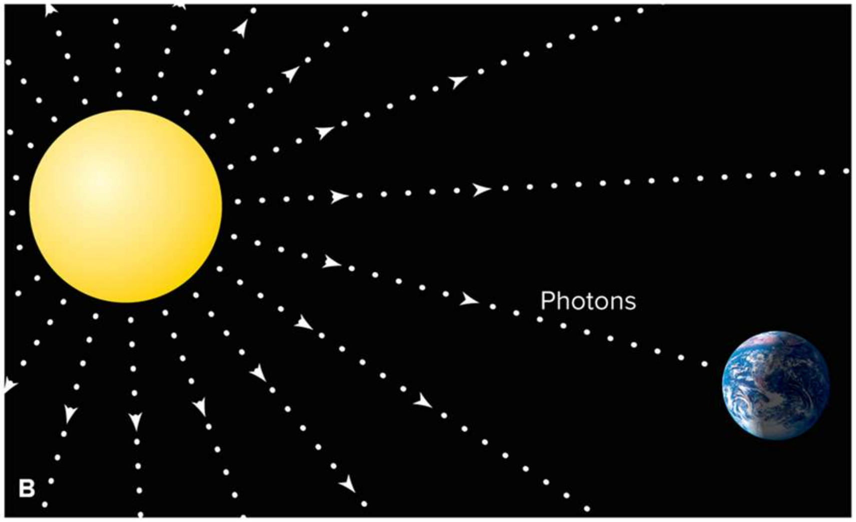
- The speed of light in transparent materials is dependent on color.
    - Fundamental reason telescopes work the way they do!

Sometimes light can be modeled as a wave…



- The wave travels as a result of a fundamental relationship between electricity and magnetism.
- A <u>changing</u> magnetic field creates an electric field and a <u>changing</u> electric field creates a magnetic field.

…and sometimes it can be modeled as a particle!



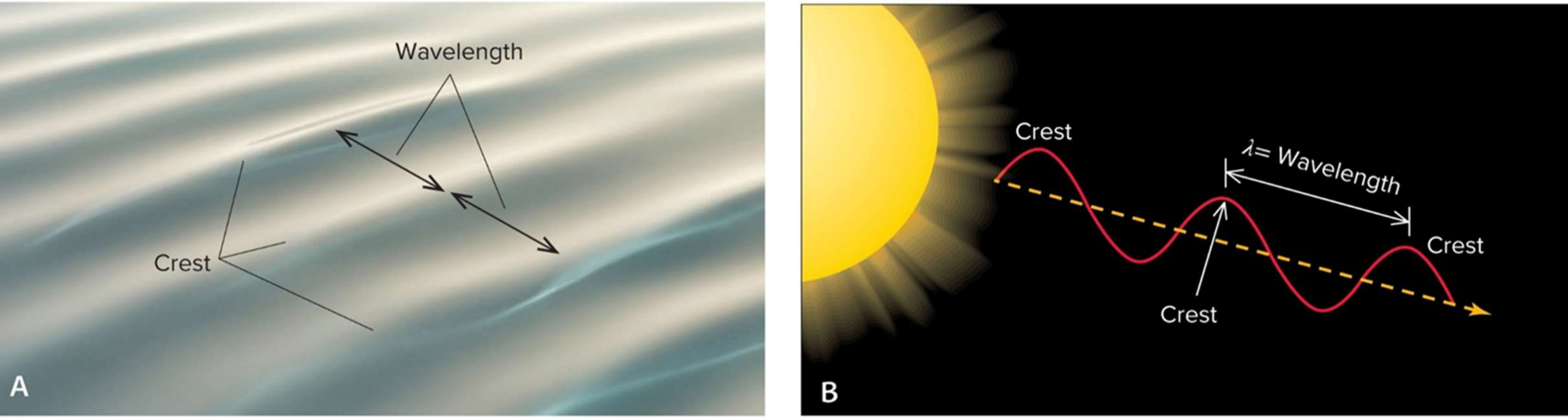
- Light thought of as a stream of particles called ***photons.***
- Each photon particle carries energy, depending on its ***frequency*** or ***wavelength.***

So which Model Do We Use?

Well, it depends!

- In a vacuum, photons travel in straight lines, but behave like waves.
- Sub-atomic particles also act as waves.
- *Wave-particle duality:* All particles of nature behave as both a wave and a particle.
- The model we use to describe light's behavior depends on the situation.
- We concentrate on the wave picture henceforth.

Parts of a Wave

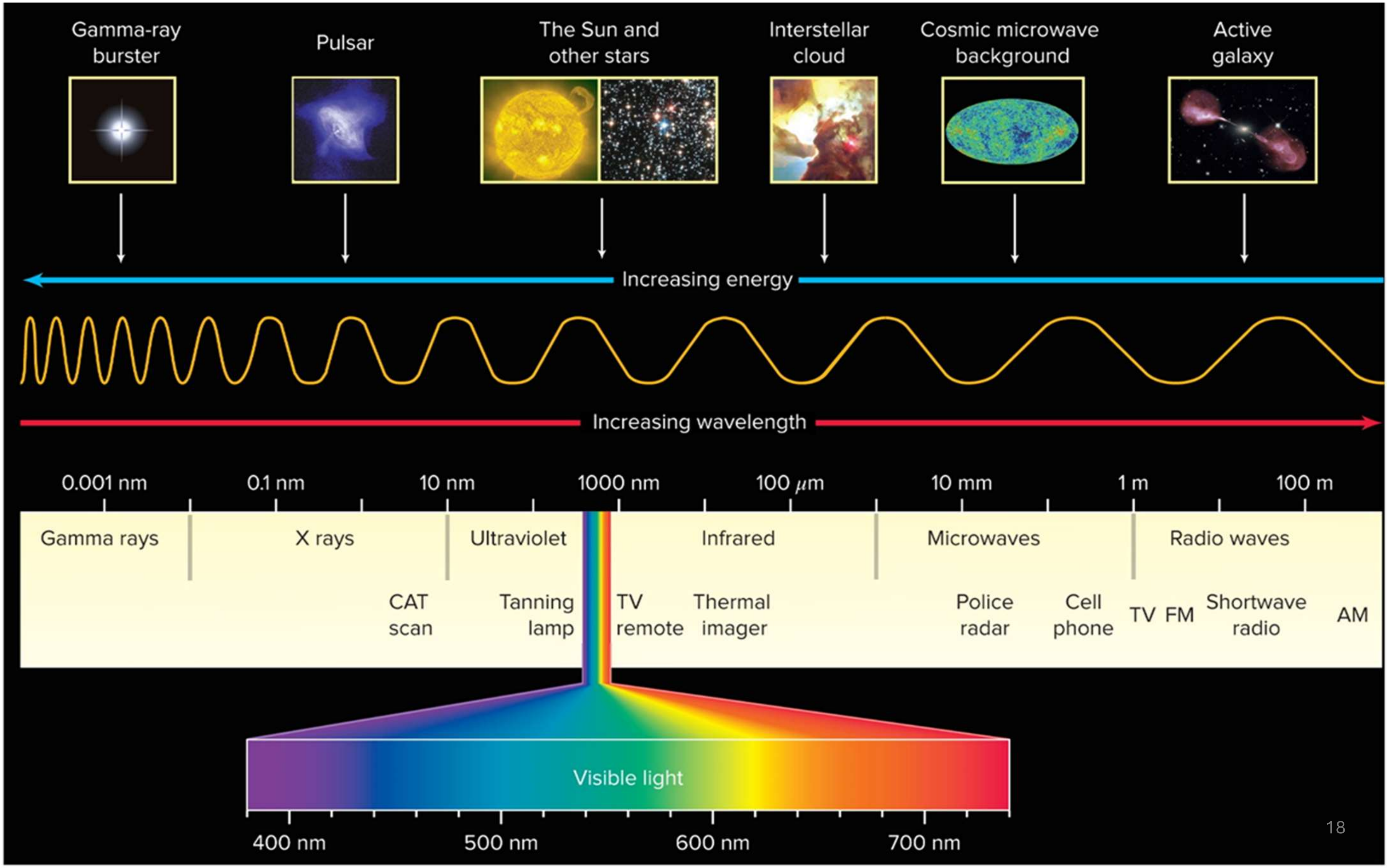


- a: © Phil Ashley/stone/Getty Images

Colors to which the human eye is sensitive is referred to as the ***visible spectrum***.

In the wave theory, color is determined by the light’s ***wavelength*** (symbolized as λ)

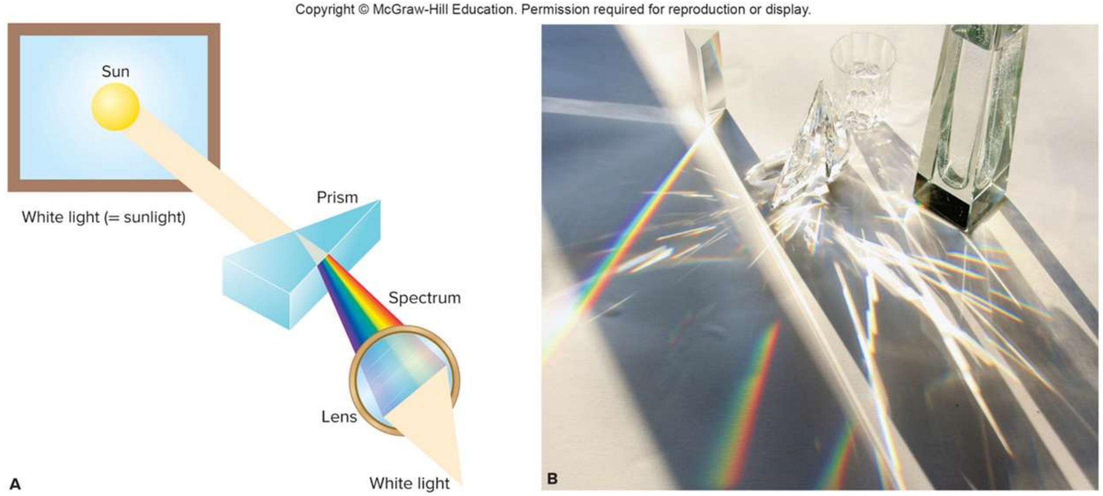
- The ***nanometer*** (10^{-9}m) is the convenient unit.
- Red = 700 nm (longest visible wavelength), violet = 400 nm (shortest visible wavelength).


Gamma-ray burster
Pulsar
The Sun and other stars
Interstellar cloud
Cosmic microwave background
Active galaxy
Increasing energy
Increasing wavelength
0.001 nm
0.1 nm
10 nm
1000 nm
100 μm
10 mm
1 m
100 m
Gamma rays
X rays
Ultraviolet
Infrared
Microwaves
Radio waves
CAT scan
Tanning lamp
TV remote
Thermal imager
Police radar
Cell phone
TV
FM
Shortwave radio
AM
Visible light
400 nm
500 nm
600 nm
700 nm

Frequency

- Sometimes it is more convenient to talk about light's frequency
- ***Frequency*** (or *v*) is the number of wave crests that pass a given point in 1 second (measured in Hertz, Hz).
- Important relation: $v \lambda = c$.
- Long wavelength = low frequency.
- Short wavelength = high frequency.

White Light – A Mixture of all Colors



- A prism demonstrates that white light is a mixture of wavelengths by its creation of a spectrum.
- Additionally, one can recombine a spectrum of colors and obtain white light.

- b: S.E Schneider

Wednesday / Thursday (February 11 – 12)

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will be able to determine the reasons for using different types of filters when observing celestial bodies
- D: by working with my partner to complete and assignment, taking notes, and participating in a class discussion.
- A: infrared, x-ray, ultraviolet, radio waves
- Y: What benefits are there to using different filters in astronomical photography?

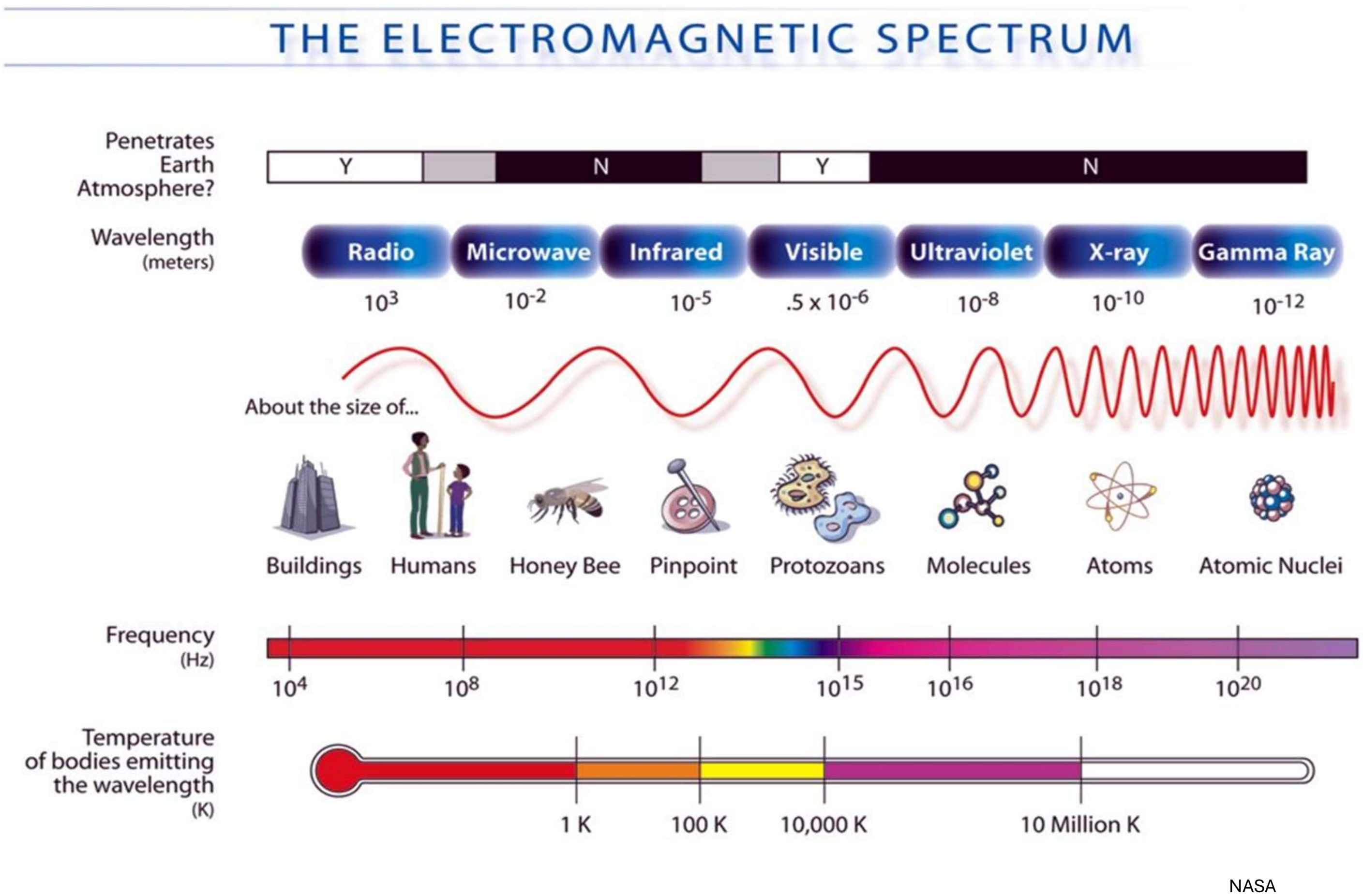
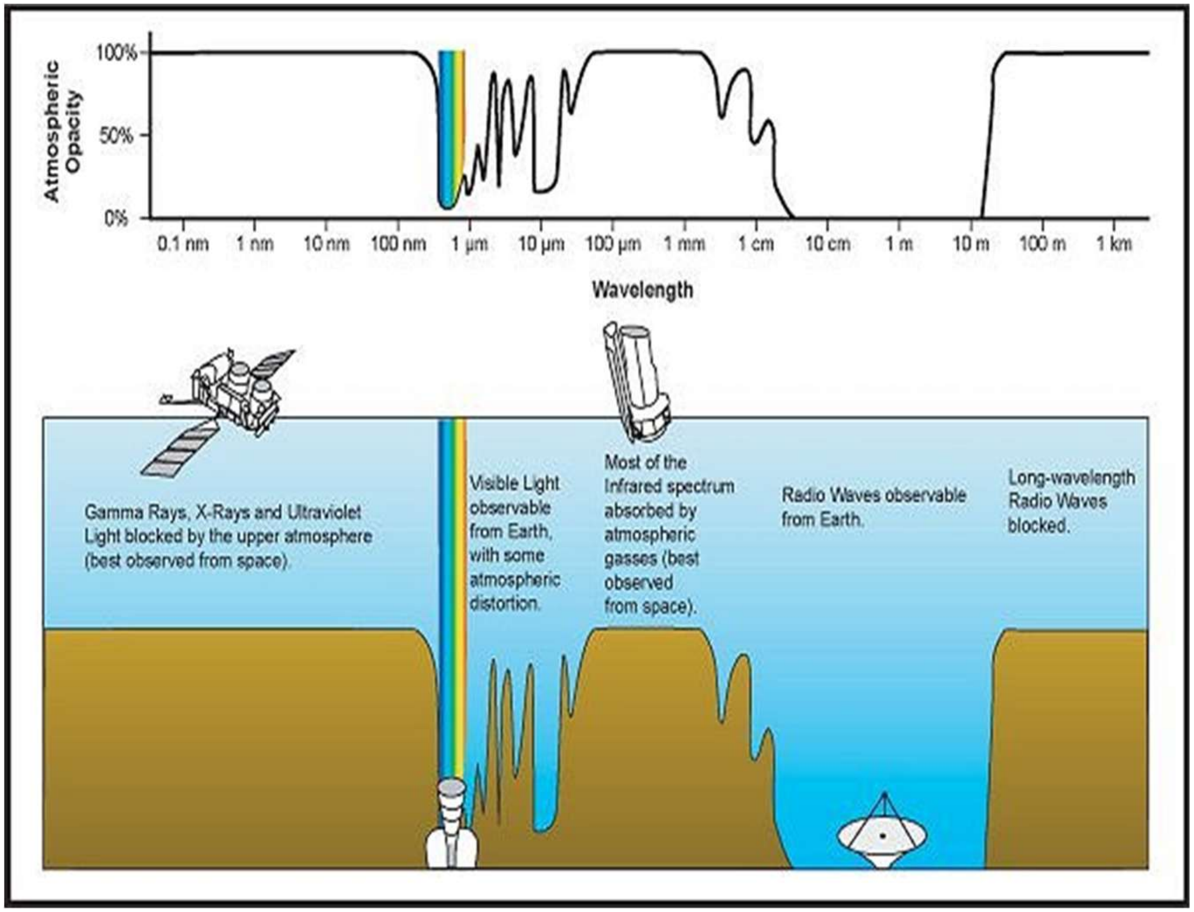

THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K
NASA

Figure 2



Atmospheric Windows

NASA/IPAC

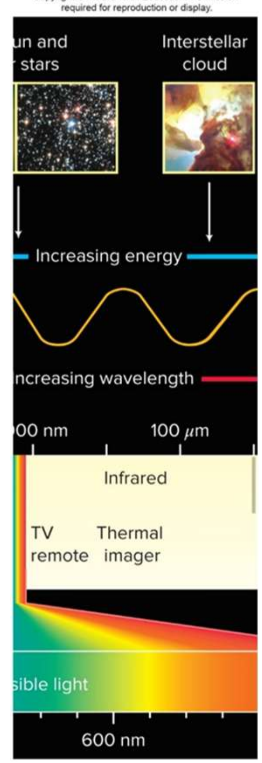
Figure 3

The Electromagnetic Spectrum

- The ***electromagnetic spectrum*** is composed of radio waves, microwaves, infrared, visible light, ultraviolet, x rays, and gamma rays.
    - Longest wavelengths are more than 10^3 km.
    - Shortest wavelengths are less than 10^{-18} m.
- Various instruments used to explore the various regions of the spectrum.

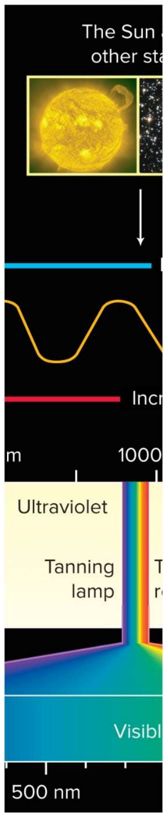
Infrared Radiation

- Sir William Herschel (around 1800) showed heat radiation related to visible light.
- He measured an elevated temperature just off the red end of a solar spectrum – ***infrared*** energy.
- Our skin feels infrared as heat.



- (Other stars): NASA and The Hubble Heritage Team (STScI/AURA)

Ultraviolet Light

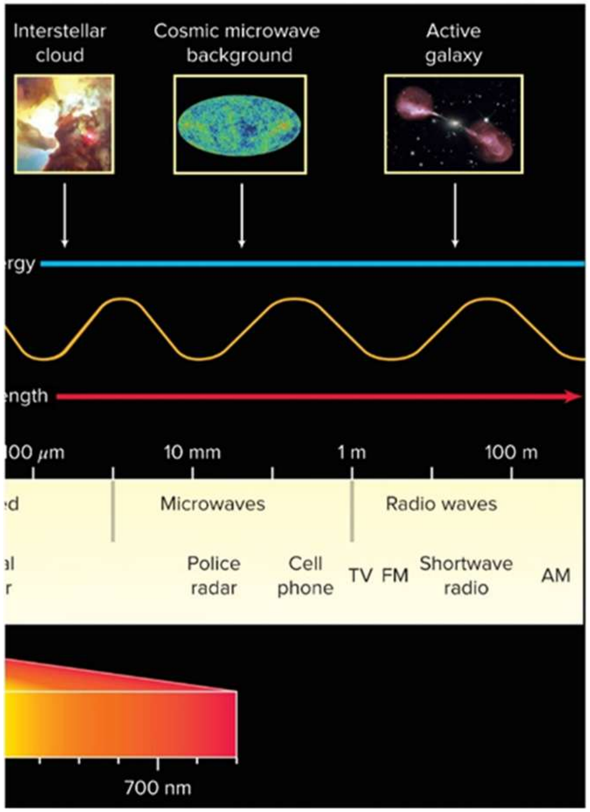


- J. Ritter in 1801 noticed silver chloride blackened when exposed to "light" just beyond the violet end of the visible spectrum.
- Mostly absorbed by the atmosphere.
- Responsible for suntans (and burns!).

- (the sun): ESA/NASA/SOHO

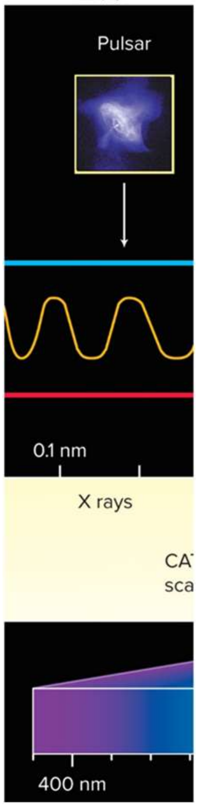
Radio Waves

- Predicted by Maxwell 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.



- (Intersterllar cloud): A, Caulet (ST-ECF, ESA) and NASA; (Cosmic microwave background): ESA and Plank Collaboration/JPL/NASA; (Active galaxy): © NG Image/Alamy Stock Photo

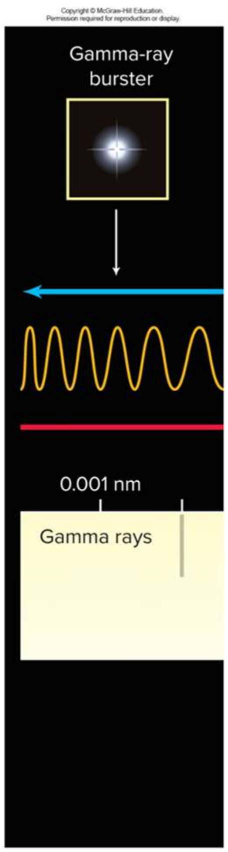
X-Rays



- Roentgen discovered X rays in 1895.
- First detected beyond Earth in the Sun in late 1940s.
- Used by doctors to scan bones and organs.
- Used by astronomers to detect black holes and tenuous gas in distant galaxies.

- (Pulsar): NASA/CXC/SAO

Gamma Rays



- Gamma Ray region of the spectrum still relatively unexplored.
- Atmosphere absorbs this region, so all observations must be done from orbit!
- We sometimes see bursts of gamma ray radiation from deep space.

Energy Carried by Electromagnetic Radiation

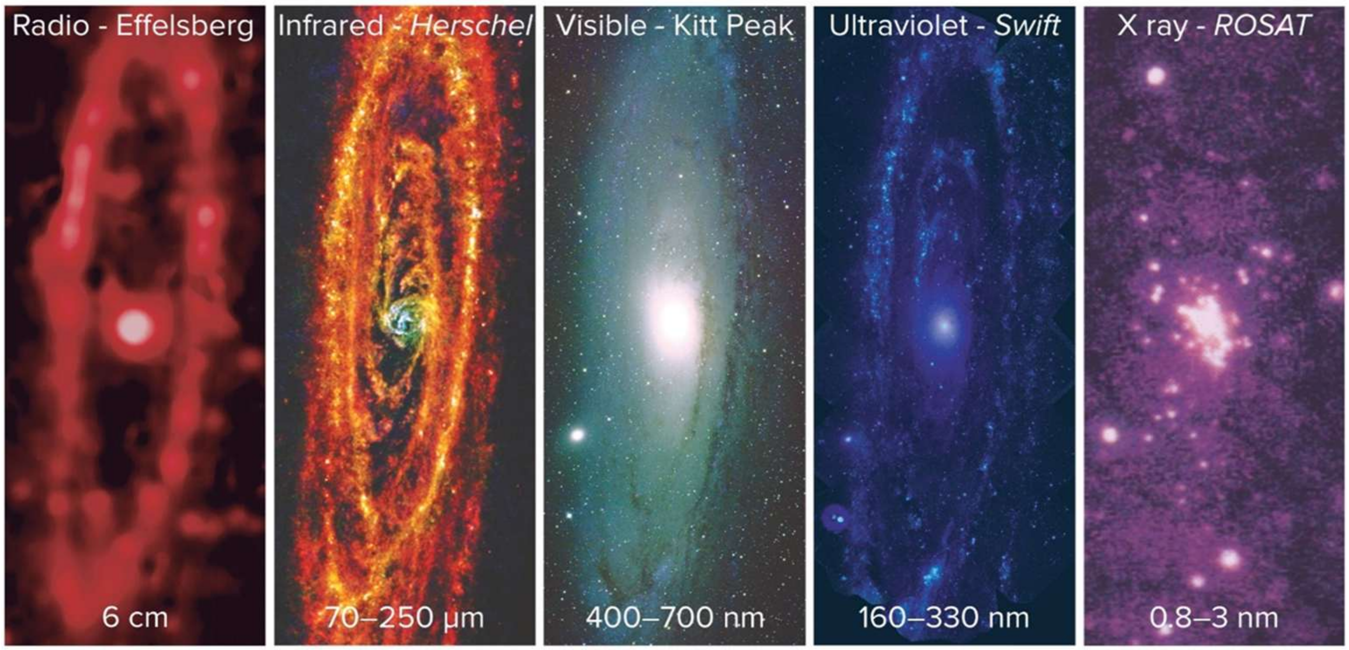
- Each photon of wavelength λ carries an energy E given by:

$$E = \frac{hC}{\lambda}$$

where *h* is Planck's constant

- Notice that a photon of short wavelength radiation carries more energy than a long wavelength photon.
- Short wavelength = high frequency = high energy.
- Long wavelength = low frequency = low energy.

Different Wavelengths, Different Science



- We see different phenomena in different wavelengths.
- Visible light shows the distribution of stars.
- Infrared reveals dust in the galaxy.
- X-rays reveal supernovae, etc.

Friday (February 13th)

- No School.

Tuesday / Wednesday (Feb 17 & 18)

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will be able to understand the colors of stars based on their heat
- D: by taking notes, participating in a class discussion, and completing a stellarium assignment.
- A: Wien’s Law, temperature, color
- Y: How does size of a start and its temperature affect the color?

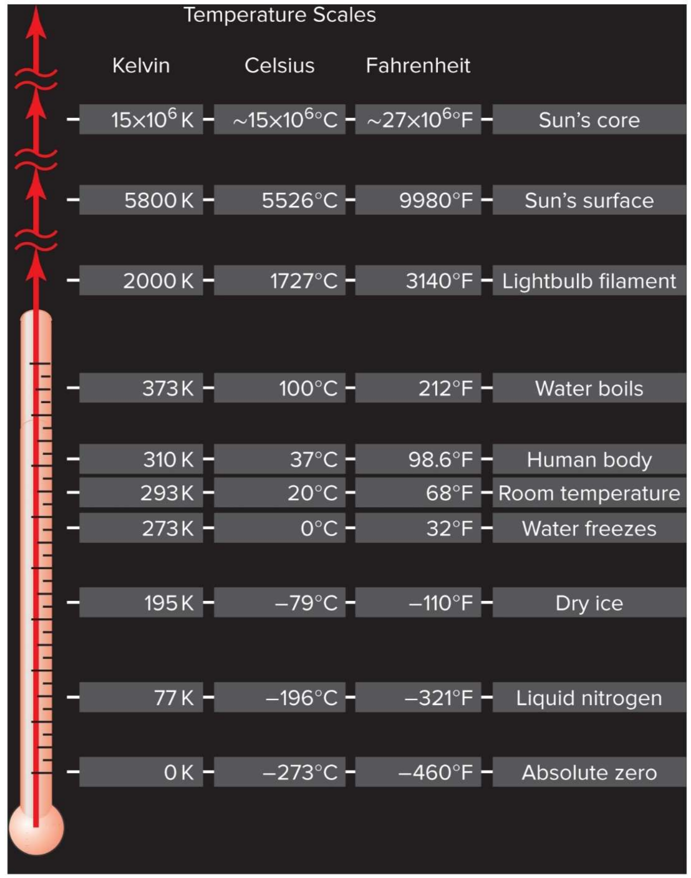
Matter and Heat

- The Nature of Matter and Heat.
- The ancient Greeks introduced the idea of the atom (Greek for "uncuttable"), which today has been modified to include a nucleus and a surrounding cloud of electrons.
- Heating (transfer of energy) 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 $\Rightarrow$ no negative temperatures.
- Fahrenheit and Celsius are two other temperature scales that are easily converted to Kelvin.

The Kelvin Temperature Scale

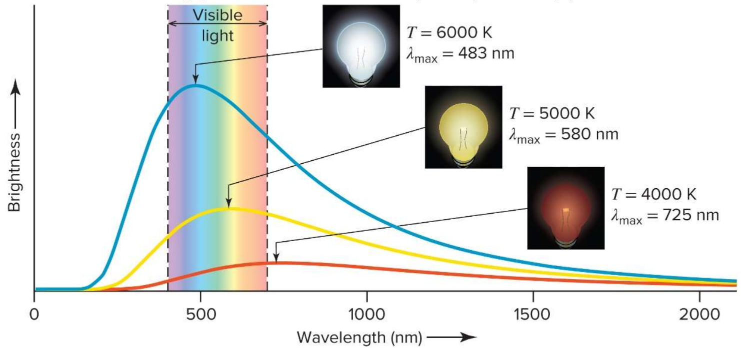


Wien's Law

- Heated bodies generally radiate across the entire electromagnetic spectrum.
- There is one particular wavelength, λ_m, at which the radiation is most intense and is given by ***Wien's Law:***

$$\lambda_m = \frac{k}{T}$$

- where k is some constant and T is the temperature of the body.



Radiation and Temperature

- Note hotter bodies radiate more strongly at shorter wavelengths.
- As an object heats, it appears to change color from red to white to blue.
- Measuring λ_m gives a body's temperature.
- Careful: Reflected light does not give the temperature.

How to Read the Color Indices of Stars

- In practice, the magnitude of a celestial object is measured in certain wavelengths or colors using filters. This is because information about the color of stars is very useful to astronomers and gives them information about the surface temperature of a star.

- The surface temperature of a star determines the color of light it emits. Blue stars are hotter than yellow stars, which are hotter than red stars.

- A hot star like Sirius, with a surface temperature of about 9,400 K emits more blue light than red light, so it looks brighter through a blue filter than through a red filter.

- The opposite is true of a cooler star such as Betelgeuse, which has a surface temperature of about 3,400 K. Betelgeuse looks brighter when viewed through a red filter than when viewed through a blue filter.

- The color index of a star is the difference between the magnitude of the star in one filter and the magnitude of the same star in another filter. Any filters can be used for color indices, but some of the most common are $B - V$ and $V - R$.
- B is blue wavelengths, V is green wavelengths and R is red wavelengths. Remember that magnitudes decrease with increasing brightness, so if $B - V$ is small, the star is bluer (and hotter) than if $B - V$ is large.

Spectral Type	Color	Temperature (K)*	Spectral Features
O		28,000-50,000	Ionized helium,especially helium
B		10,000-28,000	Helium, some hydrogen
A		7,500-10,000	Strong hydrogen, some ionized metals**
F		6,000-7,500	Hydrogen and ionized metals such as calcium and iron
G		5,000-6,000	Both metals and ionized metals, especially ionized calcium
K		3,500-5,000	Metals
M		2,500-3,500	Strong titanium oxide and some calcium

* To convert approximately to Fahrenheit, multiply by 9/5.

** Astronomers regard elements heavier than helium as metals.

Thursday / Friday (Feb 19 & 20)

Journal 5.1

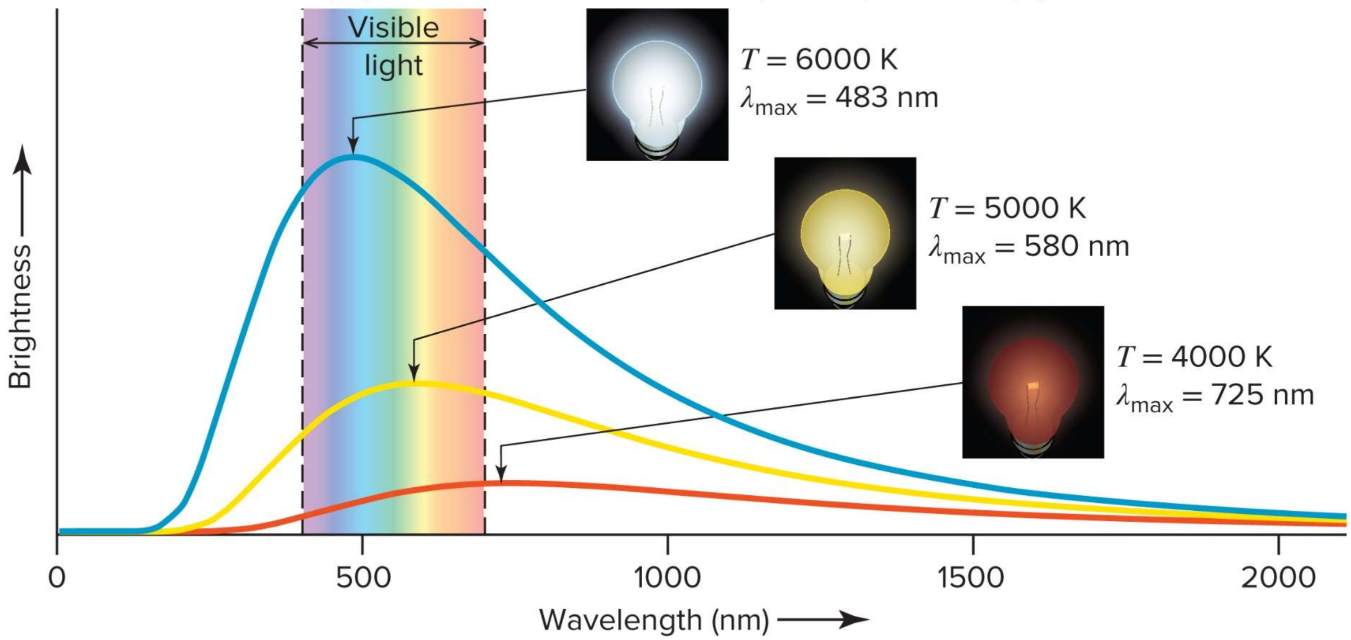
- Who inspires you to be successful?

- T: **(10) Science concepts. The student knows how astronomical tools collect and record information about celestial objects. The student is expected to:**
- **10A** investigate the use of black body radiation curves and emission, absorption, and continuous spectra in the identification and classification of celestial objects;
- O: I will understand molecular absorption of energy
- D: by taking notes and completing a PhET simulation.
- A: spetra, light, absorption, emission
- Y: How do atoms absorb energy?

Ideal Blackbodies

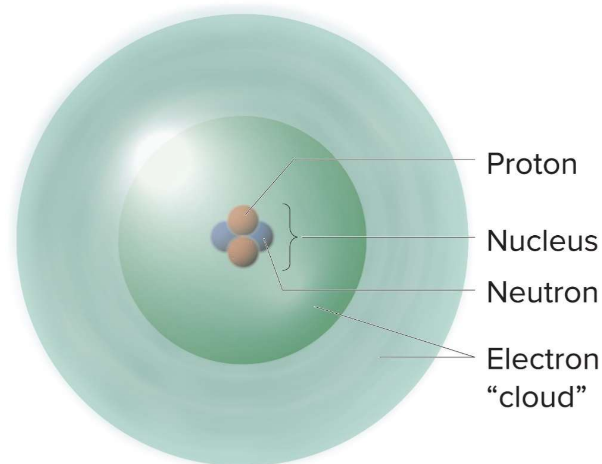
- A ***blackbody*** is an object that absorbs all the radiation falling on it.
- Since such an object does not reflect any light, it appears black when cold, hence its name.
- As a blackbody is heated, it radiates more efficiently than any other kind of object.
- Blackbodies are excellent absorbers and 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.

Blackbodies and Wien's Law



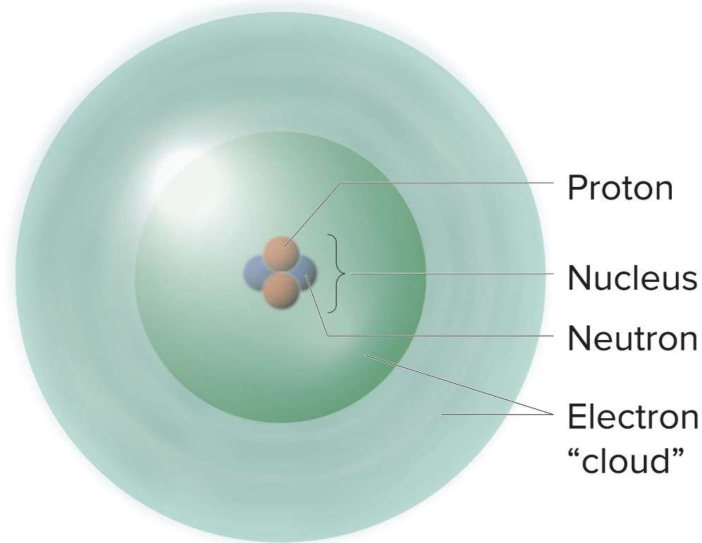
The Chemical Elements

- An ***element*** is a substance composed only of atoms that have the same number oaf protons in their nucleus.
- A neutral element will contain an equal number of protons and electrons.
- The chemical properties of an element are determined by the number of electrons.



The Structure of Atoms

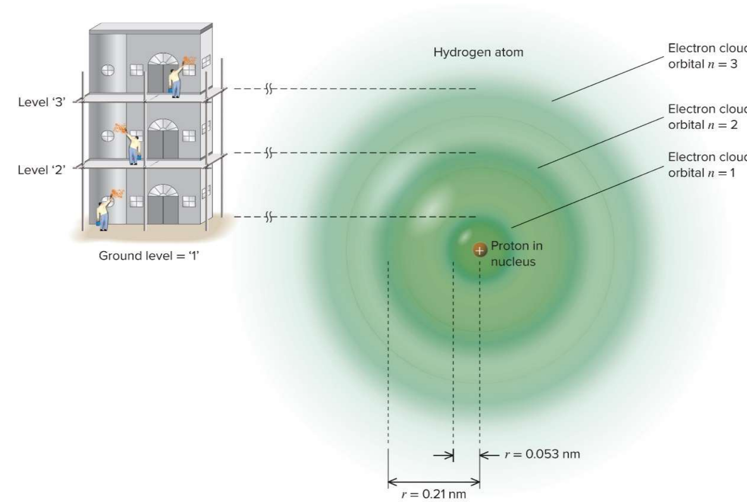
- *Nucleus* – Composed of densely packed neutrons and positively charged protons.
- *Orbitals* - Clouds of negative electrons held around nucleus by positive charge of protons.



- Typical atom size: $10^{-10}\,\mathrm{m}(=1\,\mathrm{\AA}=0.1\,\mathrm{nm})$

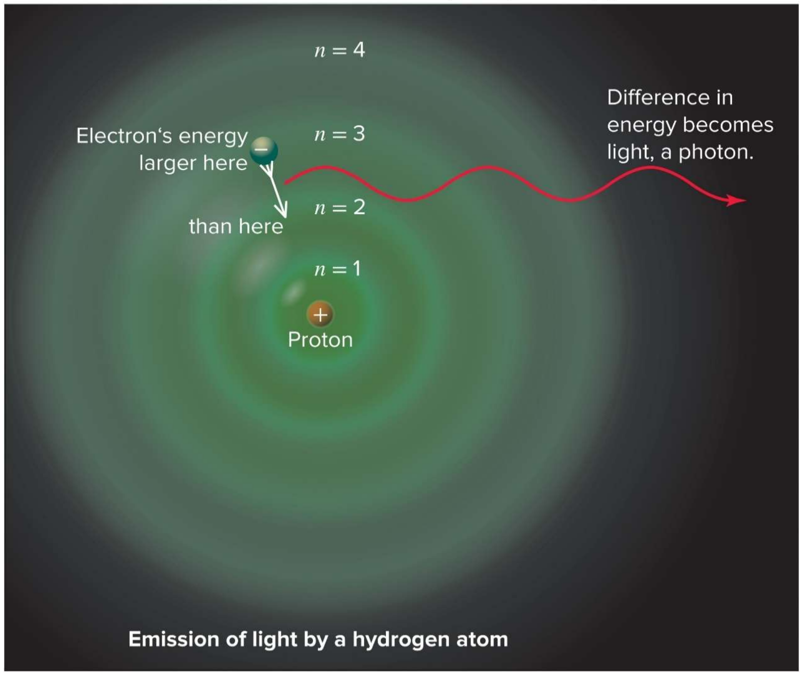
Electron Orbitals

- The electron orbitals are ***quantized,*** can only have discrete values and nothing in between.
- Quantized orbitals are the result of the wave-particle duality of matter.
- As electrons move from one orbital to another, they change their energy in discrete amounts.



Energy Change in an Atom

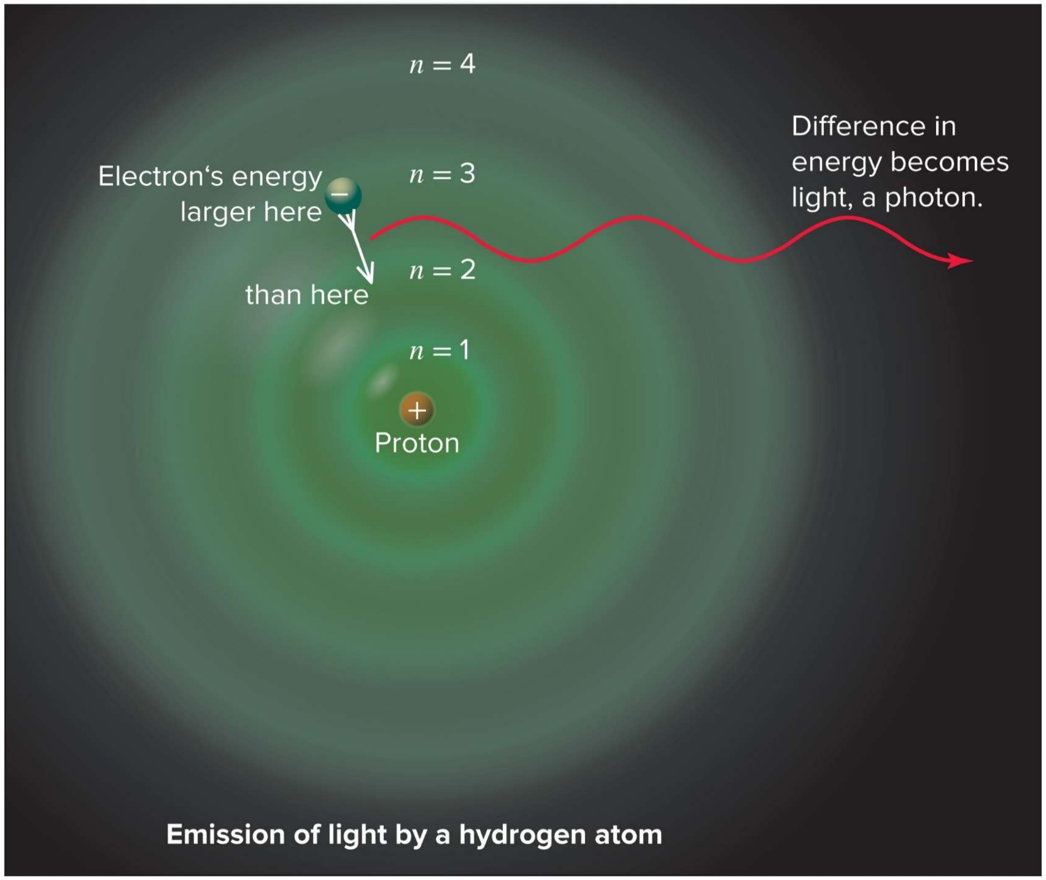
- An atom's energy is increased if an electron moves to an outer orbit – the atom is said to be ***excited.***
- An atom's energy is decreased if an electron moves to an inner orbit.



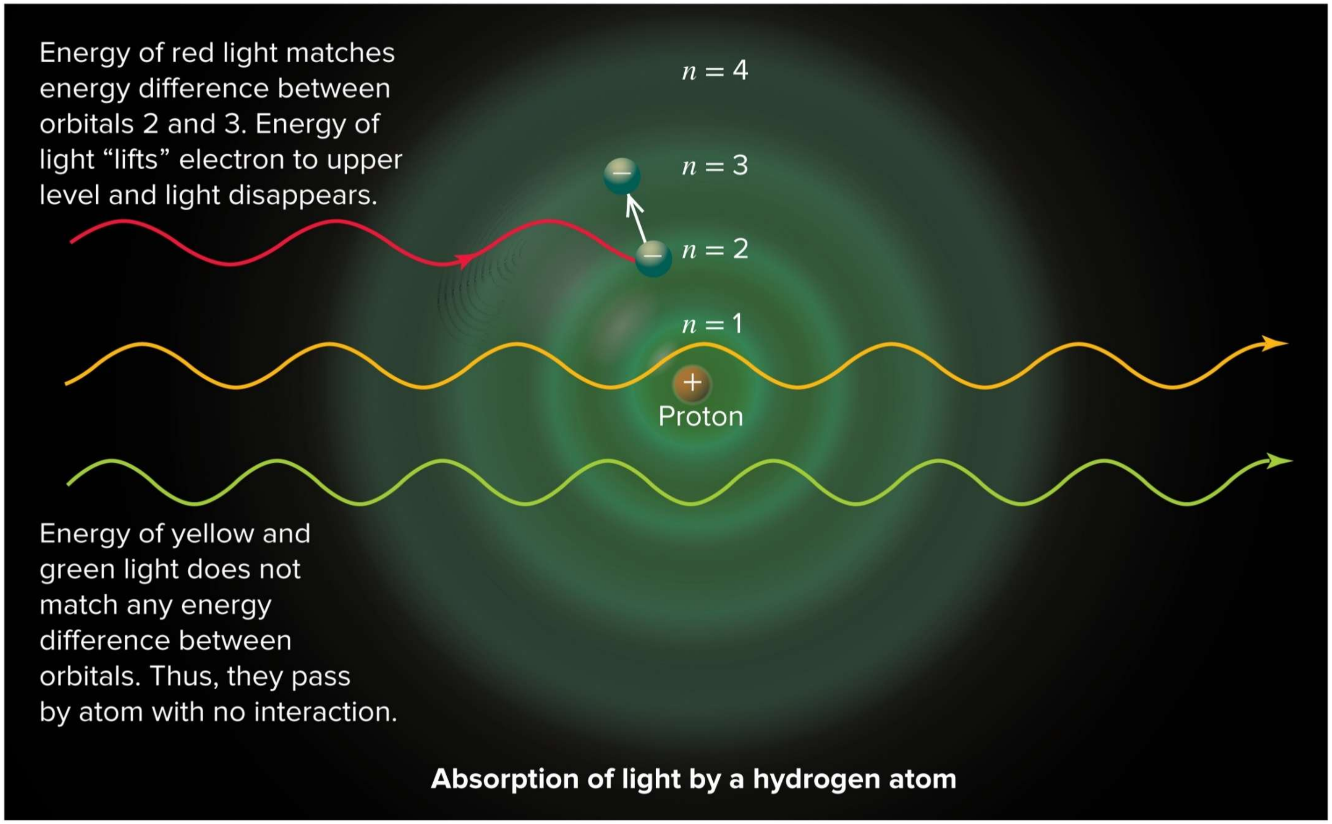
Conservation of Energy

- The energy change of an atom must be compensated elsewhere – ***Conservation of Energy.***
- ***Absorption*** and ***emission*** of EM radiation are two ways to preserve energy conservation.
- In the photon picture, a photon is absorbed as an electron moves to a higher orbit and a photon is emitted as an electron moves to a lower orbit.

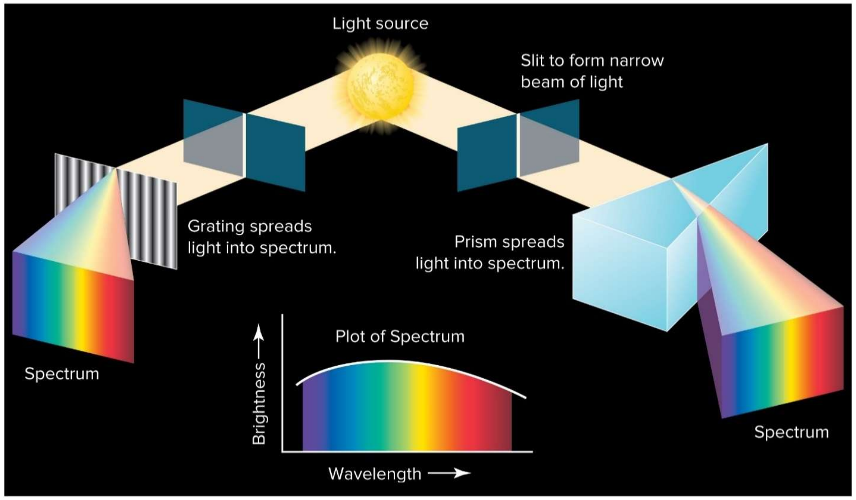
Emission


n = 4
n = 3
n = 2
n = 1
Electron's energy larger here
than here
Proton
Difference in energy becomes light, a photon.
Emission of light by a hydrogen atom

Absorption

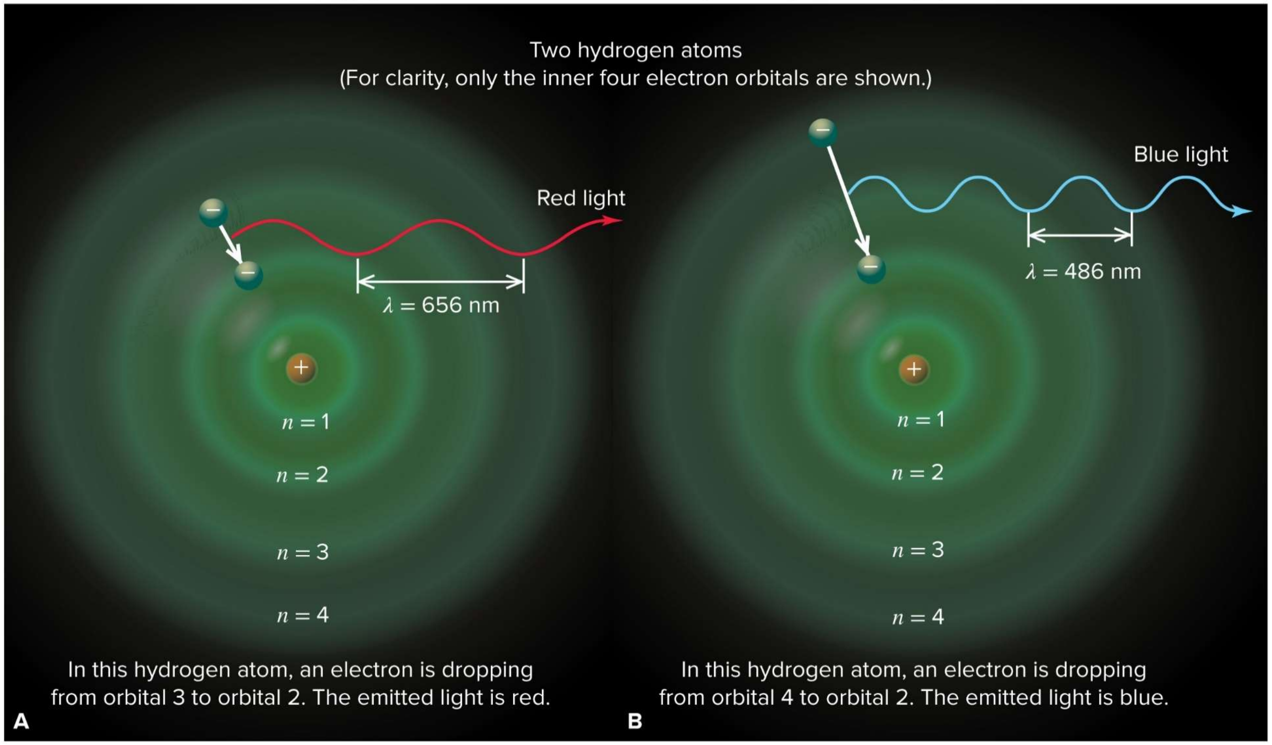

Energy of red light matches energy difference between orbitals 2 and 3. Energy of light "lifts" electron to upper level and light disappears.
n = 4
n = 3
n = 2
n = 1
Proton
Energy of yellow and green light does not match any energy difference between orbitals. Thus, they pass by atom with no interaction.
Absorption of light by a hydrogen atom

Spectroscopy



- Allows the determination of the composition and conditions of an astronomical body.
- In ***spectroscopy,*** we capture and analyze a spectrum.
- Spectroscopy assumes that every atom or molecule will have a unique spectral signature.

Formation of a Spectrum

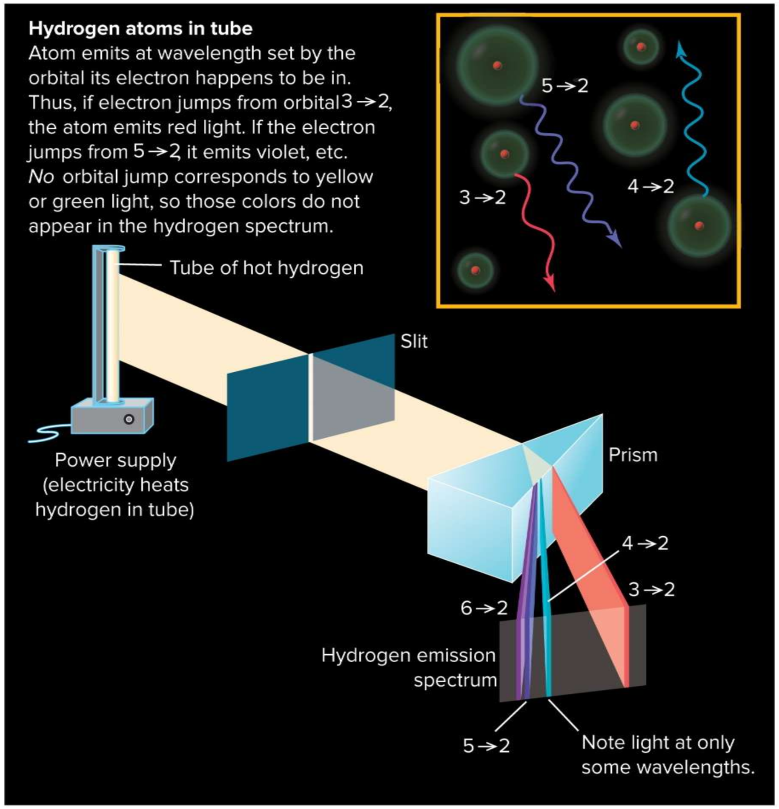


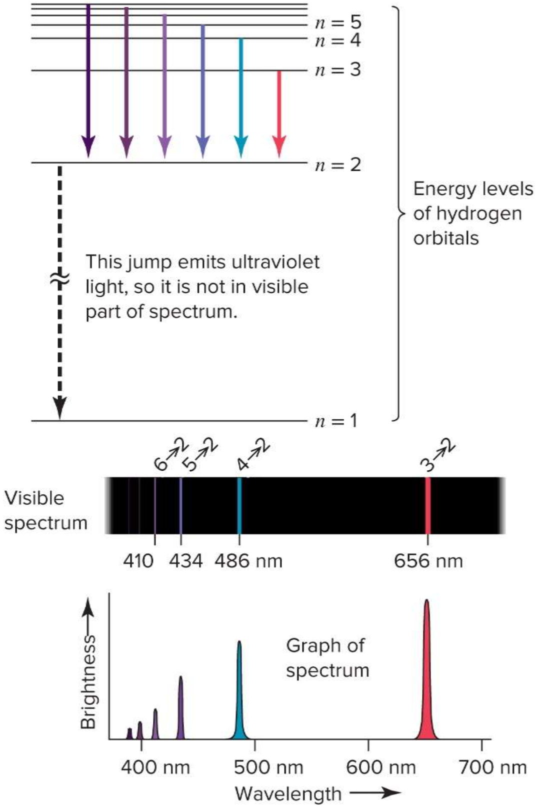
- Key Point: A transition in energy level produces or absorbs a photon

Types of Spectra

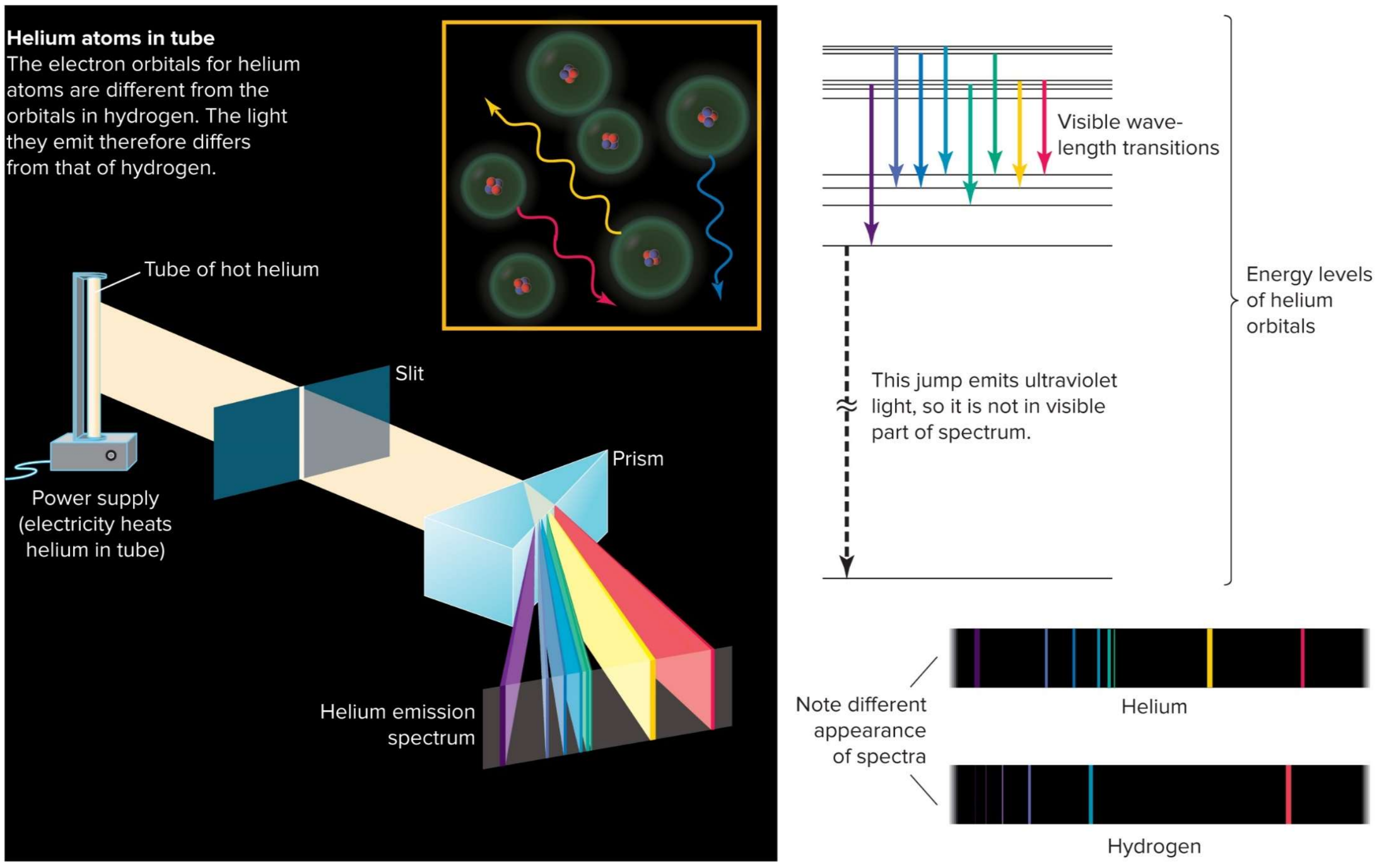
- Continuous spectrum:
  - Spectra of a blackbody.
  - Typical objects are solids and dense gases.
- Emission-line spectrum:
  - Produced by hot, tenuous gases.
  - Fluorescent tubes, aurora, and many interstellar clouds are typical examples.
- Dark-line or absorption-line spectrum:
  - Light from blackbody passes through cooler gas leaving dark absorption lines.
  - Fraunhofer lines of Sun are an example.

Hydrogen Emission Spectrum

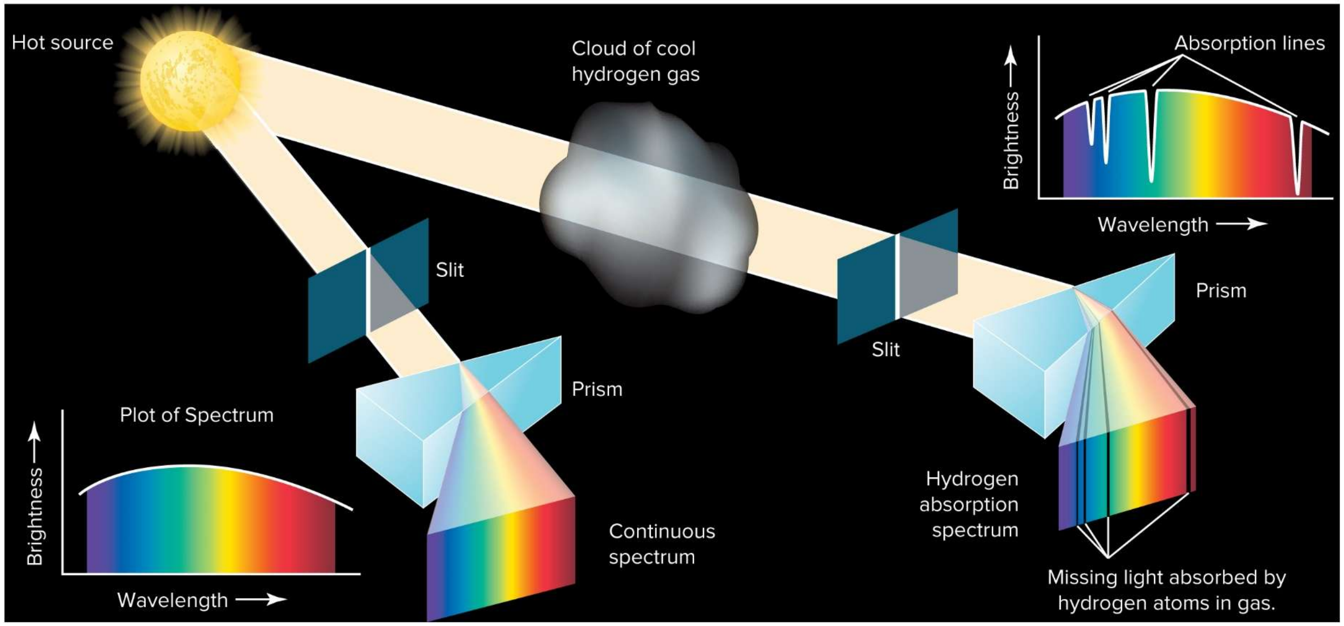




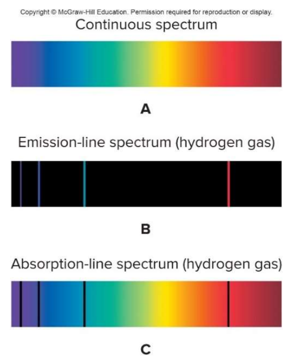
Helium Emission Spectrum

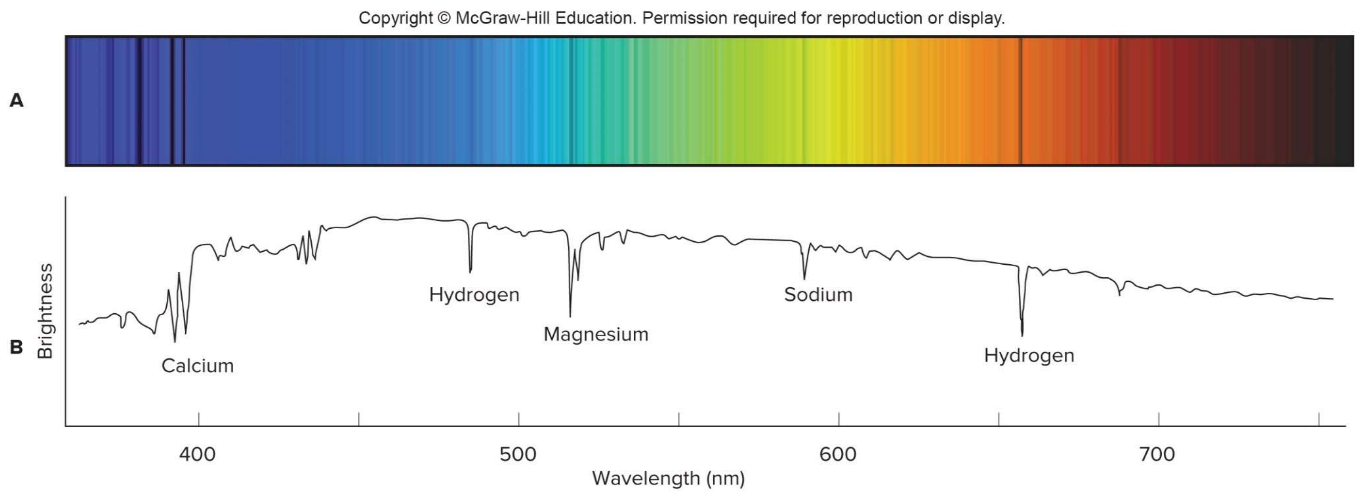


Continuous and Absorption Spectra



Astronomical Spectra





- Courtesy of Mees Solar Observatory, University of Hawali

Absorption in the Atmosphere

- Gases in 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 ***atmospheric windows,*** wavelength regions of high transparency.
- Lack of atmospheric windows at other wavelengths is the reason for astronomers placing telescopes in space.