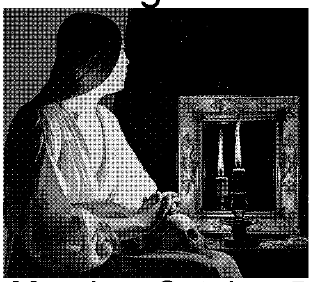
Light



Monday, October 5

Next Planetarium Shows: Tonight, Tue, Wed 7 pm

Universe contains electrically charged particles: protons (+) and electrons (-).

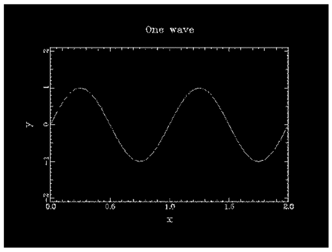
Charged particles are surrounded by electric fields and magnetic fields.

Fluctuations in those fields produce **electromagnetic waves**.

Visible light is a form of electromagnetic wave…

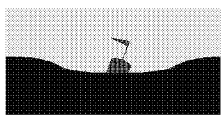
…but so are radio waves, microwaves, infrared light, ultraviolet light, X rays, and gamma rays.

Light is a **wave**.

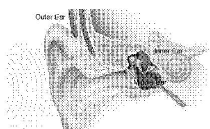


Wave = a periodic fluctuation traveling through a medium.

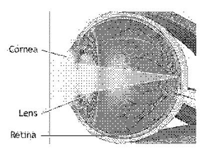
Ocean wave = fluctuation in height of water.



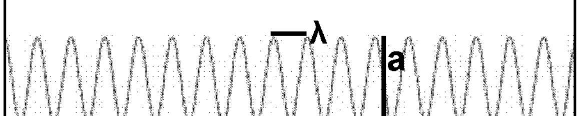
Sound wave = fluctuation in pressure.



Electromagnetic wave = fluctuation in electric and magnetic fields.



Describing a wave:



Wavelength (λ) = distance between wave crests.

Amplitude (a) = height of crests above troughs.

Frequency (f) = number of crests passing per second

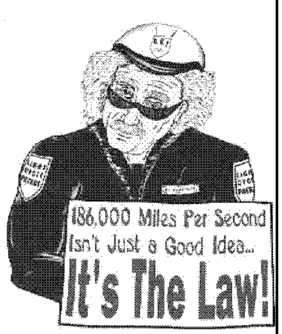
The speed of a wave equals wavelength times frequency.

$$c = \lambda \times \mathrm{f}$$

(c for "celeritas", the Latin word for "speed")

	wavelength	frequency	speed
ocean wave	100 meters	0.1 /sec	
sound wave (middle C)	1.2 m	262 /sec	
light wave (**red**)	6.6×10^{-7} m	4.5×10^{14} /sec	

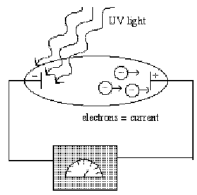
The speed of light in a vacuum is **always** c = 300,000 km/sec (186,000 miles/sec).



Light is made of **particles**.

Light shows some properties of particles, such as the **photoelectric effect**.

Particles of light, called **photons**, kick electrons out of atoms.



The **energy** of a photon is related to the **frequency** of a wave.

$$E = h \times f$$

E = energy of photon

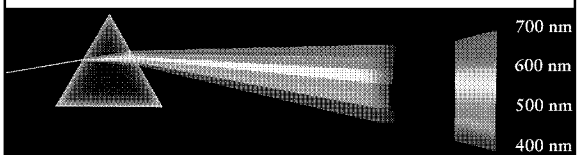
f = frequency of light wave

h = Planck's constant
(a very small number indeed)

Wave or particle?

Both.
Light has properties of **both** a wave and a stream of particles. Light follows the laws of **quantum mechanics**.

Light forms a spectrum from short to long wavelength.



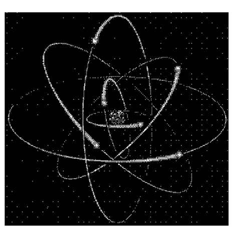
Visible light has wavelengths from 400 to 700 **nanometers**.
[1 nanometer (nm) = 10^{-9} meters]

The **COMPLETE** spectrum of light

Gamma rays (λ < 0.01 nanometers)
X rays (0.01 → 10 nm)
Ultraviolet (10 → 400 nm)
Visible (400 → 700 nm)
Infrared (700 nm → 1 mm)
Microwave (1 → 100 mm)
Radio (> 100 mm)

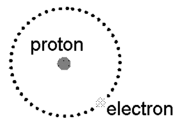
High energy photons ↓ Low energy photons

Consider an atom:
(highly schematic drawing)



A nucleus, consisting of protons and (usually) neutrons, is surrounded by a cloud of electrons.

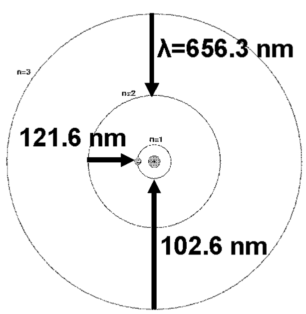
Hydrogen: one proton, one electron.



Behavior on subatomic scales is governed by **quantum mechanics**.

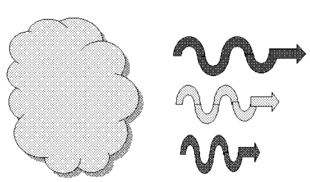
Rule: electrons can only exist in orbits of particular energy. (Small orbit = low energy, big orbit = high energy).

Electron falls from high- to low-energy orbit: energy is carried away by a photon.



Photon has a fixed **energy**, corresponding to fixed **wavelength**.

Consider a hot, low density glob of hydrogen gas.



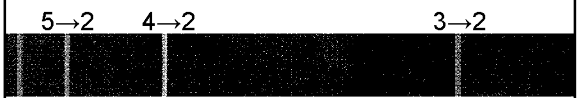
λ = 656.3 nm (3→2)

λ = 486.1 nm (4→2)

λ = 434.0 nm (5→2)

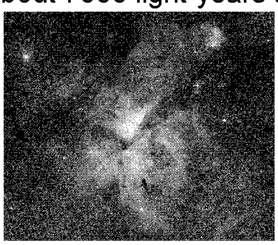
Light emitted **only** at wavelengths corresponding to energy jumps between electron orbits.

Hot, low density gas produces an **emission** line spectrum.



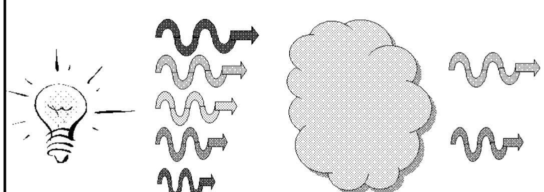
Spectrum of hydrogen at visible wavelengths.

Carina Nebula: a cloud of hot, low density gas about 7000 light-years away.



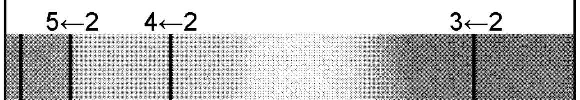
Its reddish color comes from the 656.3 nm emission line of hydrogen.

A cool, low density glob of hydrogen gas in front of a light source.



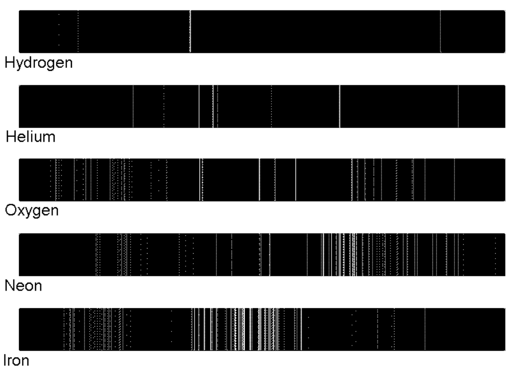
Light absorbed **only** at wavelengths corresponding to energy jumps between electron orbits.

Cool, low density gas produces an **absorption** line spectrum.

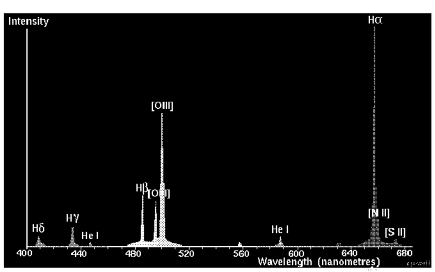


Spectrum of hydrogen at visible wavelengths.

Each element has a unique spectrum.



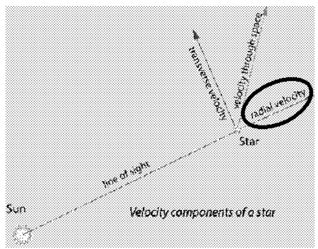
The spectrum of the Carina Nebula:



Hydrogen line at 656.3 nanometers

The **radial velocity** of an object is found from its **Doppler shift**.

Radial velocity = how fast an object is moving toward you or away from you.

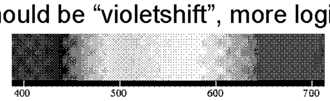


Christian Doppler (1803-1853)

Doppler shift:
If a wave source moves toward you or away from you, the wavelength changes.

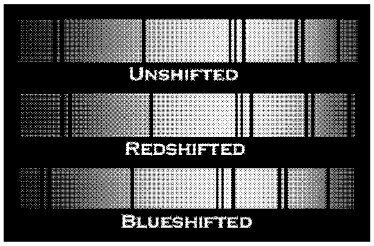
If a light source is moving **toward** you, wavelength is shorter (called “blueshift”).

(should be “violetshift”, more logically)



If a light source is moving **away** from you, wavelength is longer (called “redshift”).

Doppler shifts are easily detected in emission or absorption line spectra.



Size of Doppler shift is proportional to radial velocity:

$$\frac{\Delta\lambda}{\lambda_0} = \frac{V}{c}$$

$\Delta\lambda$ = observed wavelength shift = $\lambda - \lambda_0$

λ_0 = wavelength if source isn't moving

V = radial velocity of moving source

c = speed of light = 300,000 km/sec

Wednesday's Lecture:

What is a star?

Reminders:

Have you read chapters 1 – 3 ?
Problem Set 1 is due **Wednesday**.
Planetarium shows **Tonight, Tue, Wed**.