- Next homework due Oct 24th– this Friday at 11:50 am.

- Astronomy Club:
  http://www.astro.uiuc.edu/~uias/

Outline

- Fusion reaction in the Sun
- Neutrino astronomy
- Switch Gears to Light– hmm… Light
- Rainbow of Light
- Why is the sky blue?
- Light speed– fast but not infinite
- Light is a wave and a particle
- The Electromagnetic Spectrum– Radio waves to Gamma rays
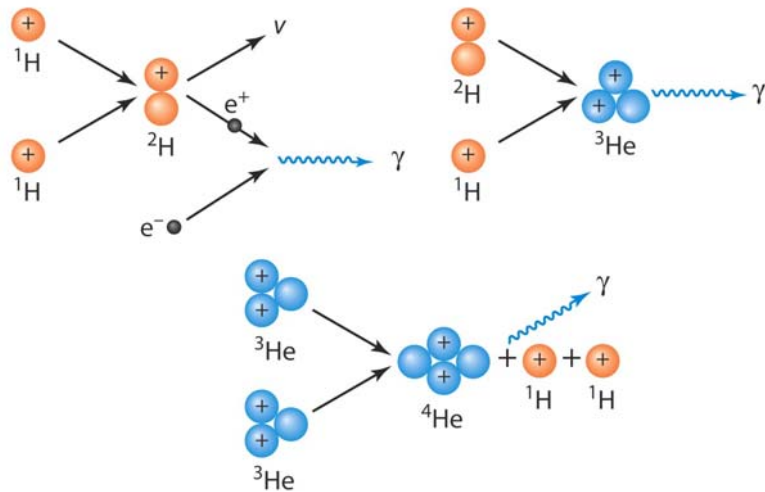
Exam 1 Results

Average: 28.1 or 70.4%

Questions Correct
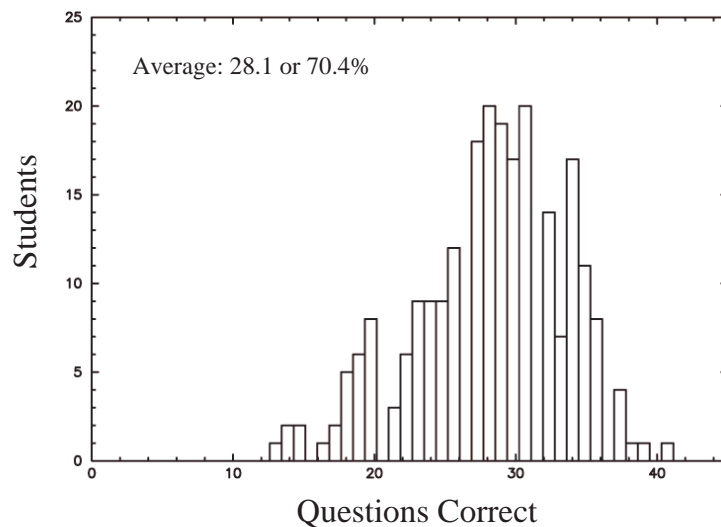
Nuclear Reactions in the Sun

- Chain: 4 protons ⟹ helium

- first step in chain:

$$p + p \rightarrow [np] + e^+ + \nu$$

- start with 2 particles (Nuclei of hydrogen— 2 protons)
- end up with 4 particles (two of which are glued together)
- deuterium, positron, and neutrino

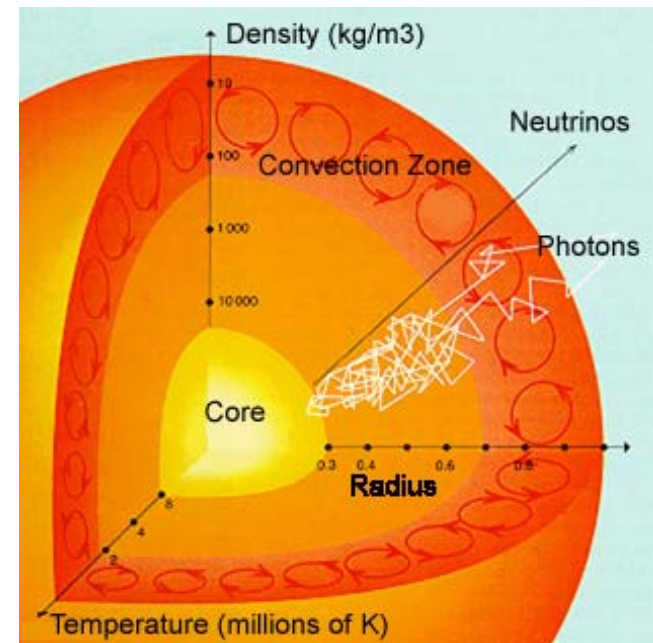# Nuclear Fusion in the Sun's Interior

The Proton-Proton Cycle

The Interior of the Sun

The Evidence

How do we know these nuclear reactions occur in the Sun?

Neutrinos from Sun are ***observed***

Detect in huge underground experiments

- *Why huge?*
- *Why underground*?

Neutrino Observatories

I.   vats of chlorine (cleaning fluid!) in S. Dakota gold mine

$\nu + \text{chlorine} \rightarrow \text{argon}$

collect argon atoms: radioactive!

Neutrino Observatories

II. vats of gallium metal
    under mountain in Italy

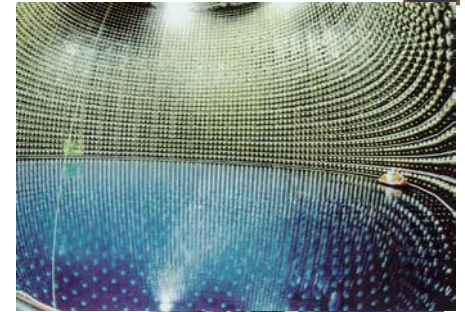$\nu + \text{gallium} \rightarrow \text{germanium}$
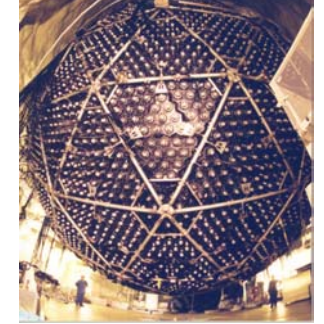
collect germanium atoms

Neutrino Observatories

III. vats of pure water in
     Japanese, Canadian
     mines

$\nu + e$ at rest $\rightarrow e$ moving fast
- see tiny flashes of light
  from "kicked" electrons
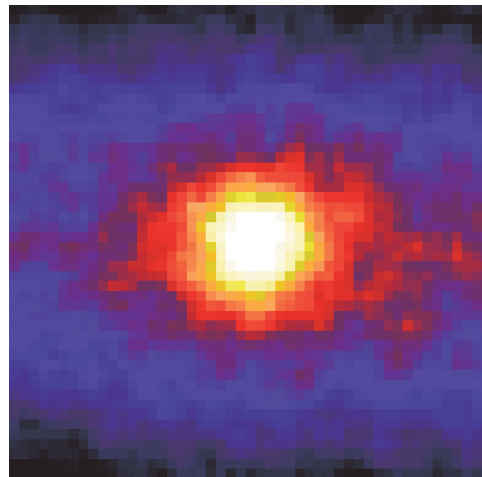
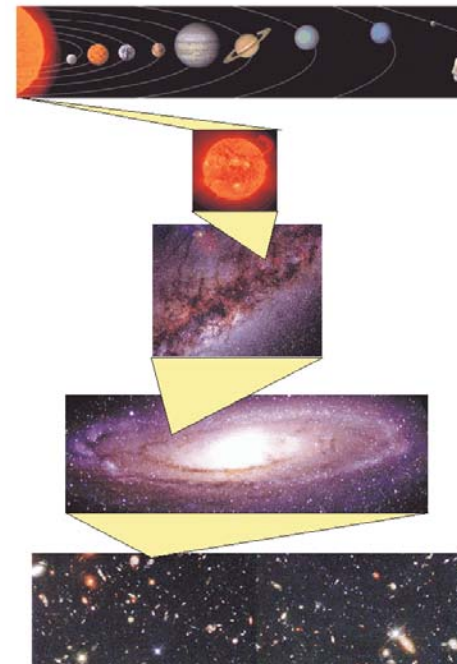## Results and Implications:
Neutrino Astronomy

Results:
- All experiments detect neutrinos
- Water experiments show they come from the Sun!

1. **Proof** that Sun powered by nuclear fusion
   - *Why?*
2. Neutrino experiments are telescopes
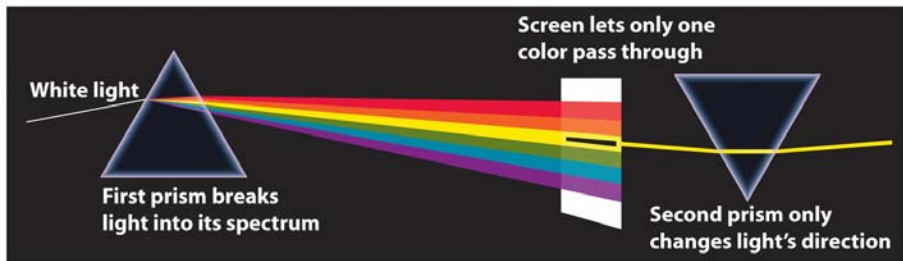   - Open new window to cosmos!

Astronomy:
The Big Picture

We must better understand light, how it is emitted, and how astronomers collect and analysis it.

Back to Chapters 3 & 4!

Visible light is composed of all the colors of the rainbow

A prism breaks white light into its component colors or spectrum

First prism breaks light into its spectrum

Screen lets only one color pass through

Second prism only changes light's direction

Oct 20, 2003 — Astronomy 100 Fall 2003

Name Some things that shine by (emit) their own light?

Light bulbs

Stars
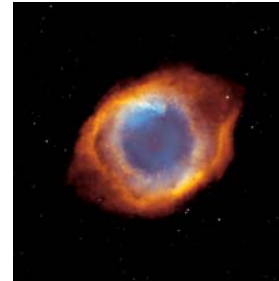
Nebulae
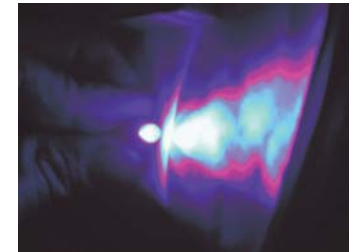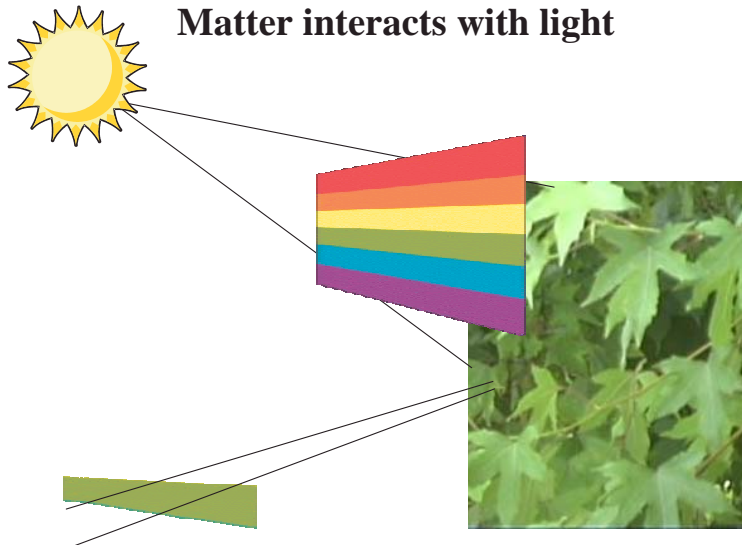
Light-emitting diodes (LEDs)

Oct 20, 2003 — Astronomy 100 Fall 2003

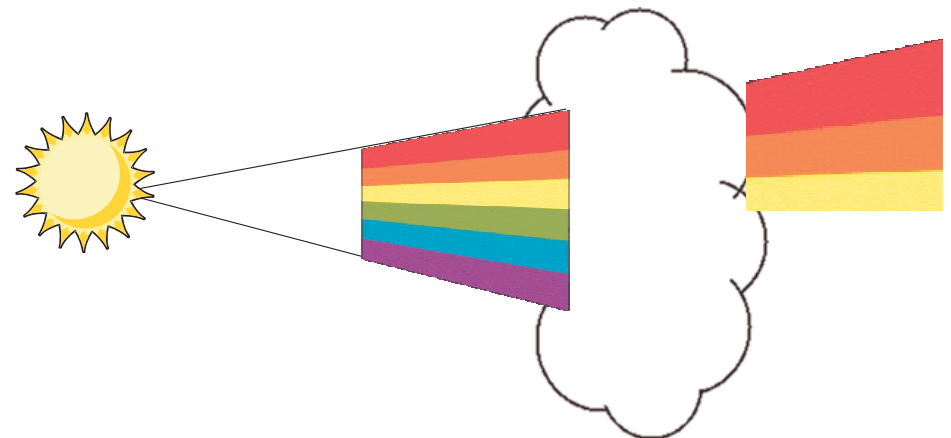**Matter interacts with light**

Reflection

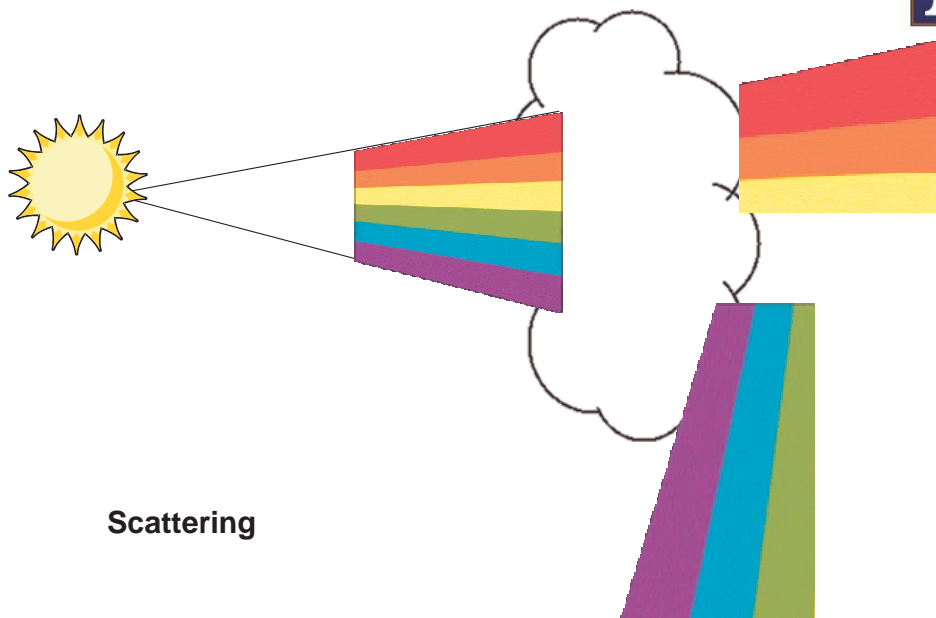Oct 20, 2003 — Astronomy 100 Fall 2003

Matter interacts with light

Absorption

Oct 20, 2003 — Astronomy 100 Fall 2003

Matter interacts with light

Scattering

Why is the Sky Blue?

Visible Light Spectrum

R O Y G B I V

long wavelength
low frequency

short wavelength
high frequency

Least readily scattered
part of spectrum.

Most readily scattered
part of spectrum.

Atmospheric nitrogen and oxygen scatter violet light most easily, followed by blue light, green light, etc. But our eyes notice the blue scattered light the most.

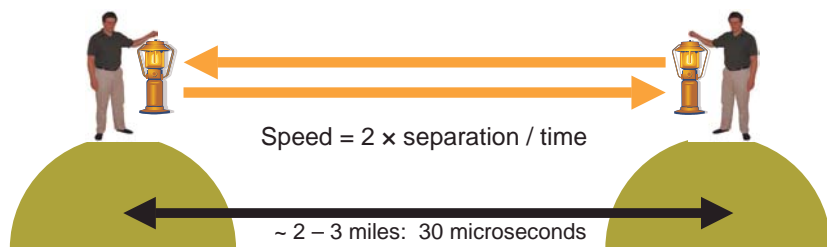http://www.glenbrook.k12.il.us/gbssci/phys/Class/light/u12l2f.html

Mars?

Light travels with a finite speed

Ancient Greeks (except for Empedocles) believed speed of light was infinite

Galileo realized that "very fast" is not the same as "infinite" – first to suggest an experiment to measure speed of light

Speed = 2 × separation / time

~ 2 – 3 miles: 30 microseconds

At least 10 times the speed of sound.
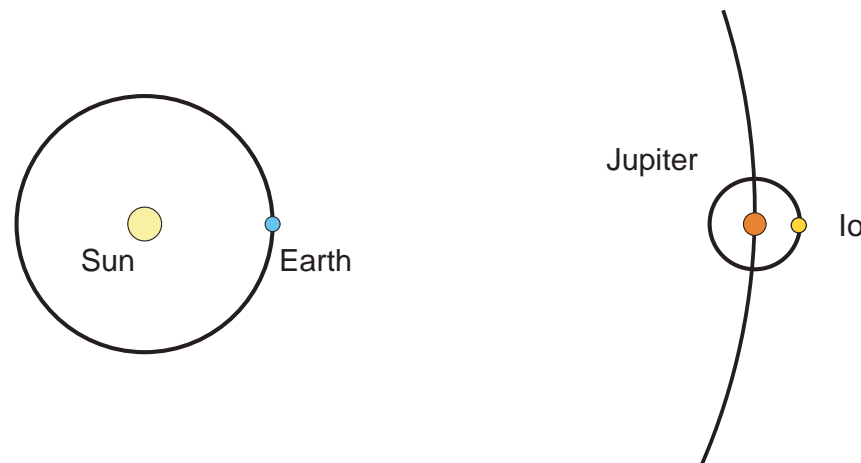

Light travels with a finite speed

First actual measurement by Ole Roemer in 1676 using Jupiter's moon Io – eclipses by Jupiter delayed by several minutes (16 mins) every six months because of extra light travel distance

Sun   Earth

Jupiter

Io

Light travels with a finite speed

- Nowadays we **define** the speed of light to be 2.99792458×10^8 m/s

- The **second** is defined very precisely using atomic clocks (9.192631770×10^9 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom at 0 K, if you must know)

- Thus the **meter** is defined as the distance traveled by light in vacuum during $1/(2.99792458 \times 10^8)$ second

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A Light Year

The **light-year**
- Distance that light travels in one year
- Speed of light: 3.00×10^5 km/sec
- Seconds in one year:

$$\left(60\,\frac{\text{sec}}{\text{min}}\right) \times \left(60\,\frac{\text{min}}{\text{hour}}\right) \times \left(24\,\frac{\text{hour}}{\text{day}}\right) \times \left(365\,\frac{\text{days}}{\text{year}}\right) = 3.16 \times 10^7 \text{ sec}$$

so 1 light year = $(3.00 \times 10^5$ km/sec$) \times (3.16 \times 10^7$ sec$)$ = 9.42×10^{12} km

- Nearest star (Proxima Centauri) is about 4.2 light years away.
- Analogous to saying: Chicago is about 2 hours away.

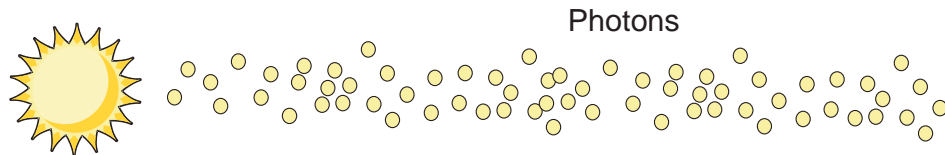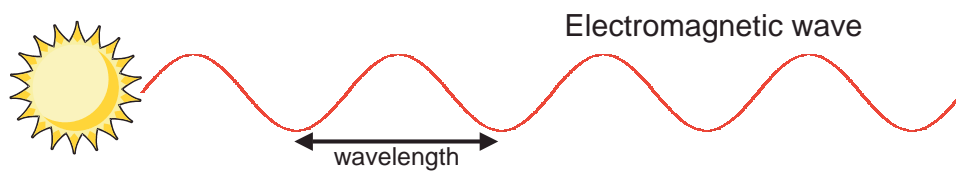## What is light?

Newton: light is composed of a large number of particles

Photons

Hooke and Huygens: light is composed of waves

Electromagnetic wave

wavelength

It turns out that both viewpoints are correct.

Thomas Young: Light is a wave
Double-slit experiment (1801)
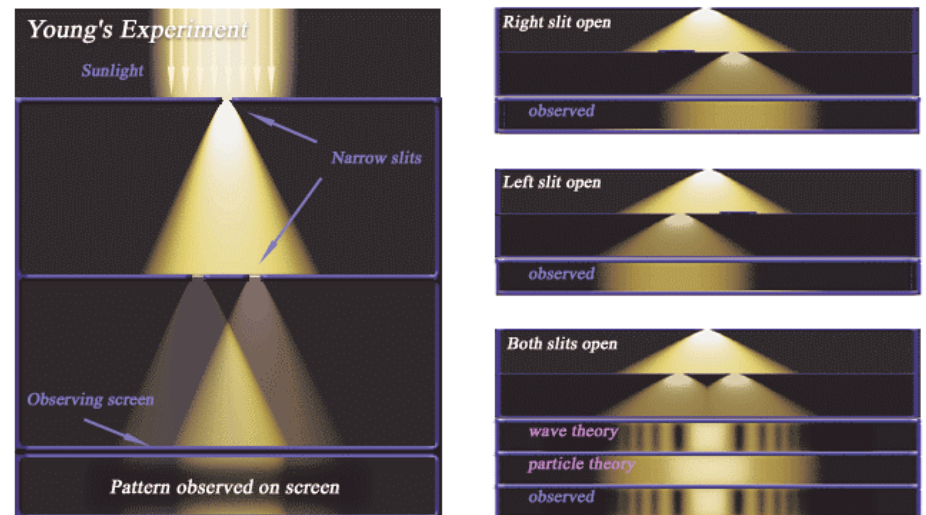
Wikipedia

James Clerk Maxwell:
Light is a traveling electromagnetic wave (1862)

► Unified electromagnetism and optics
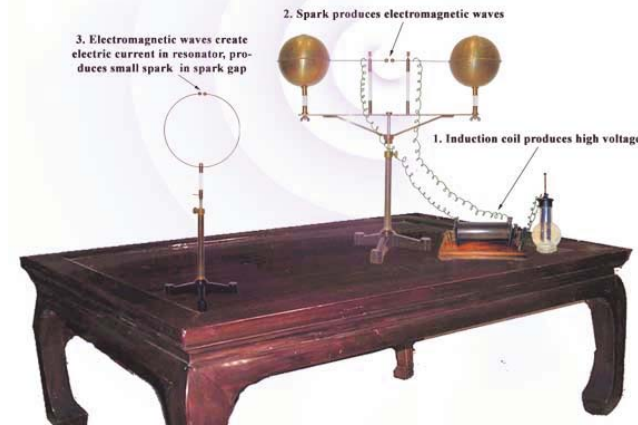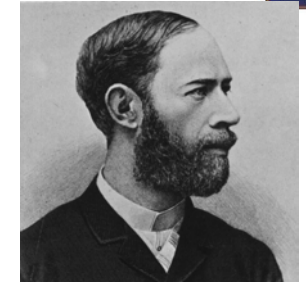► Predicted the existence of invisible forms of light
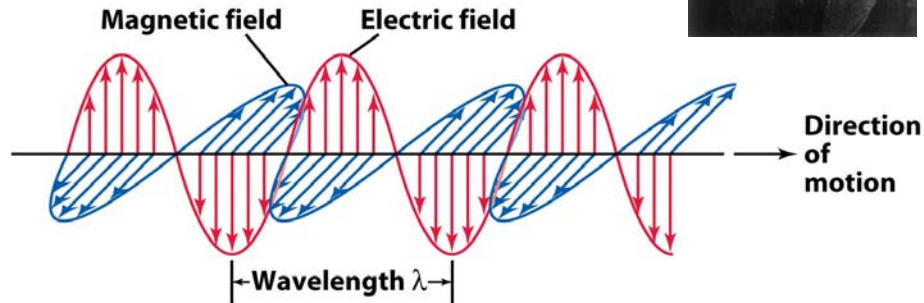
The discovery of radio waves

Heinrich Hertz's experiment (1885)

The discovery of X-rays
Wilhelm Roentgen (1895)

Light is also made of particles!

• **Photoelectric effect:** if we shine light onto a metal surface, electrons pop out
• Only happens if the **frequency** of the light is high enough
• Increasing the **intensity** of the light doesn't help

http://www.dac.neu.edu/physics/b.maheswaran/
phy1121/data/ch08/anim/anim0801.htm

Albert Einstein interpreted this to mean: light can also behave like a particle – the low-frequency light particles (**photons**) don't have enough energy to knock out electrons. He won the Nobel Prize for this work.,
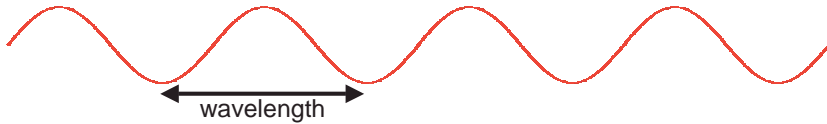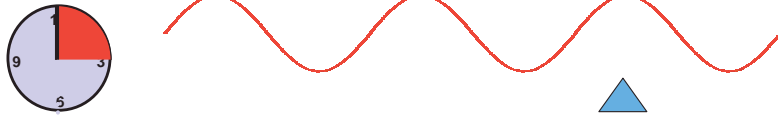
Light is both particle and wave

Wavelength is the distance between successive crests (or troughs) of a wave

Frequency is the reciprocal of the time between successive crests for an observer standing still as the wave goes by.

The **energy** of light particles (photons) increases as their frequency increases.
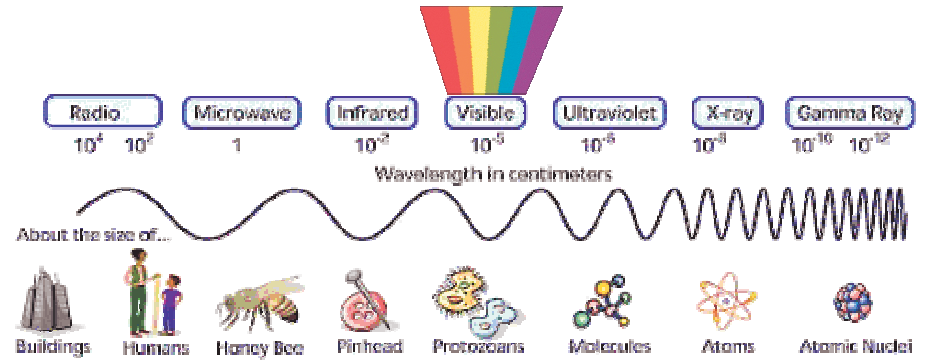
The electromagnetic spectrum

▶ Visible light is only a tiny portion of the full electromagnetic spectrum

▶ Red light has longer wavelength/lower frequency/lower energy than blue light

NASA

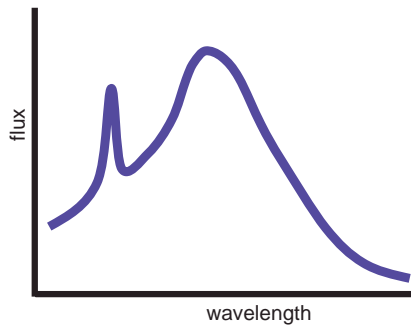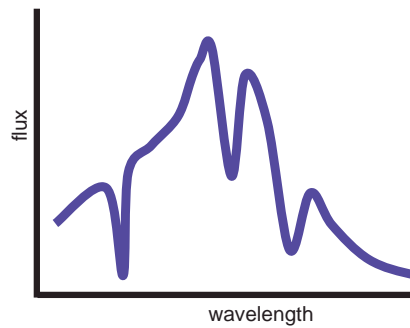## The spectrum

The "spectrum" of a light source also refers to the fractional contribution of all of the different wavelengths to its total light output.
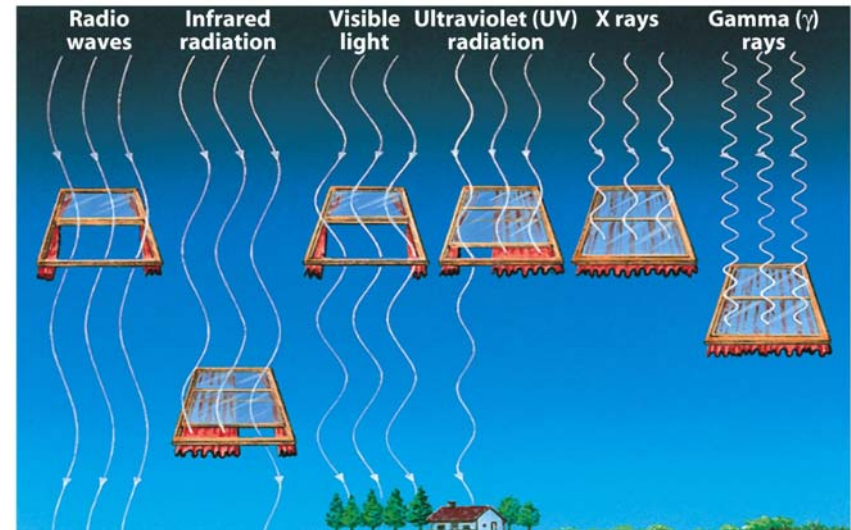

Emission

Absorption

The atmosphere absorbs some wavelengths and not others
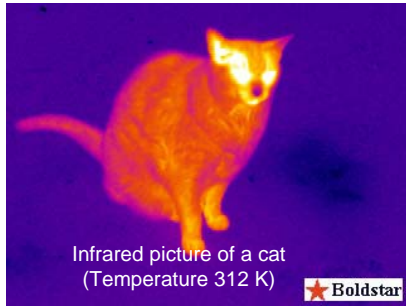
Blackbody Radiation

- Light that objects emit because of their temperature is called **blackbody radiation**
- Blackbody radiation is composed of a continuous spectrum of wavelengths
- The **hotter** an object gets, the **more intense** and **shorter wavelength** (bluer) its blackbody radiation becomes

Infrared picture of a cat
(Temperature 312 K)

★ Boldstar

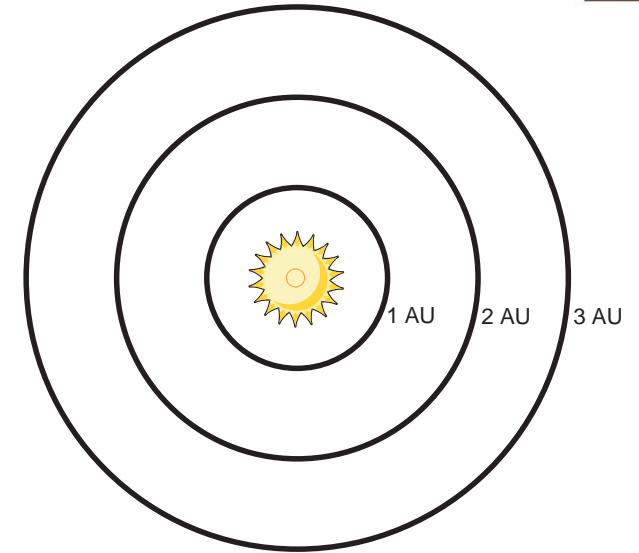Visible-light picture of a stove element
(Temperature ~ 400 K)

Flux and distance

- ▶ Area of concentric spheres increases as the square of their radii

- ▶ Same amount of light passes through each sphere

- ▶ So amount of light per unit area (ie. **flux**) decreases as the inverse square of the distance

Radius	Area/4π	Flux
1 AU	1 AU^2	1.00
2 AU	4 AU^2	0.25
3 AU	9 AU^2	0.11

1 AU   2 AU   3 AU