Astro 301/ Fall 2006

(50405)

Introduction to Astronomy

http://www.as.utexas.edu/~sj/a301-fa06

Instructor: Professor Shardha Jogee

TAs: Biqing For, Candace Gray, Irina Marinova

Lecture 12: Th Oct 12

Upcoming topics in class

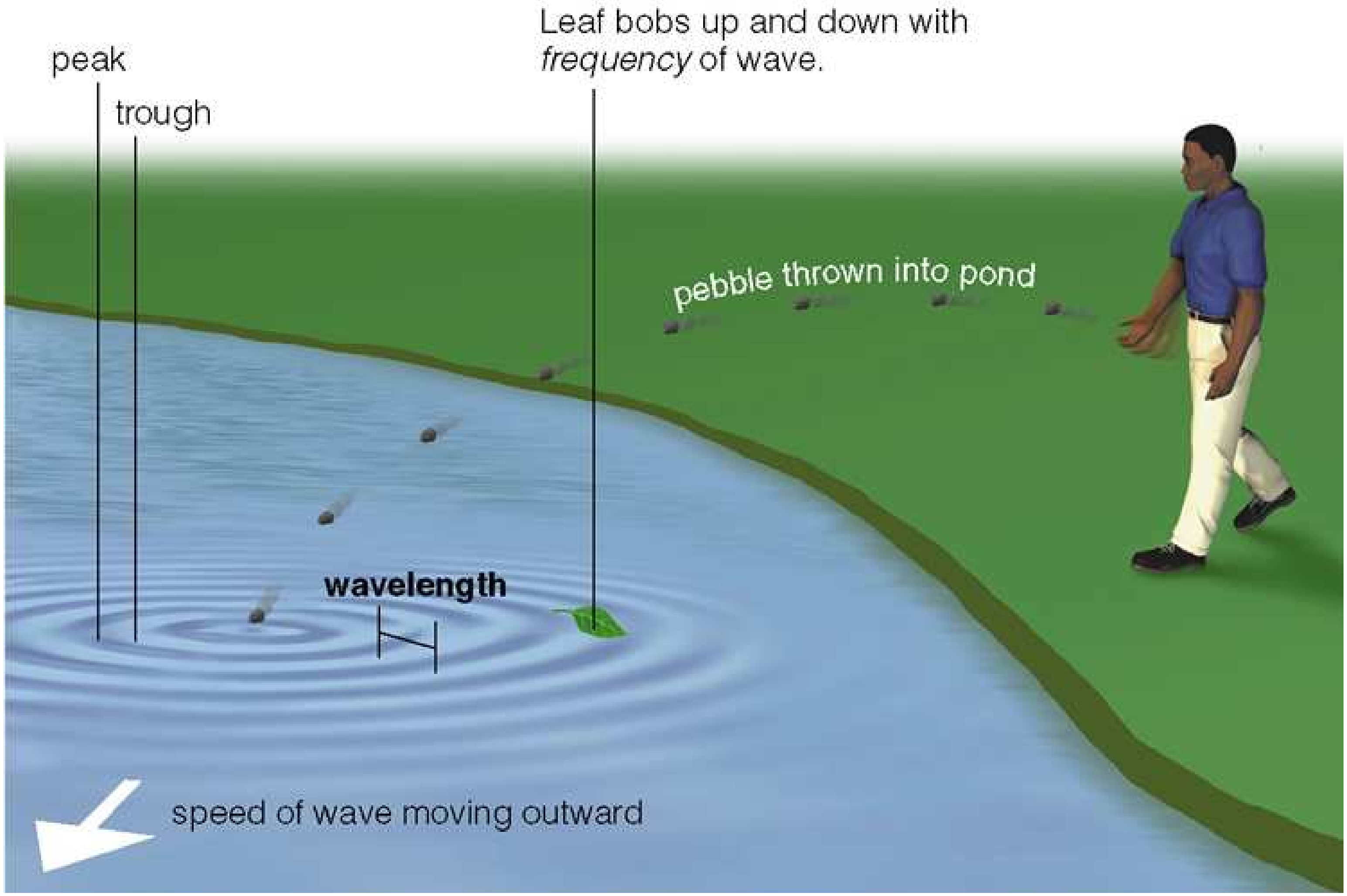
-- What is a wave? Types of waves?

-- Overview : What is light? The dual nature of light

-- Light as electromagnetic waves

How does matter emit electromagnetic waves (light)?
How do we “see” electromagnetic wavles (light)?
Wavelength, Frequency, Speed, Amplitude and Energy
Relation between speed, frequency and wavelength : $v = f \lambda$
Examples of how light behaves as electromagnetic waves

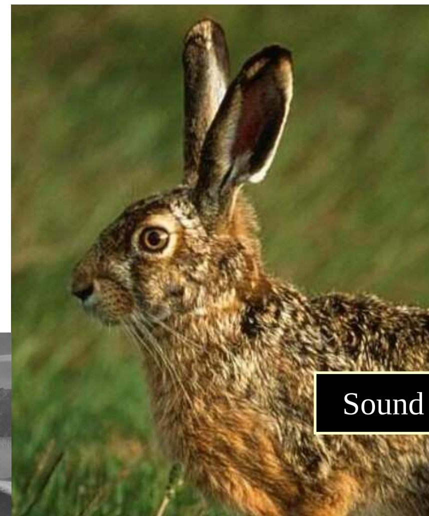
Waves Are Common in Nature



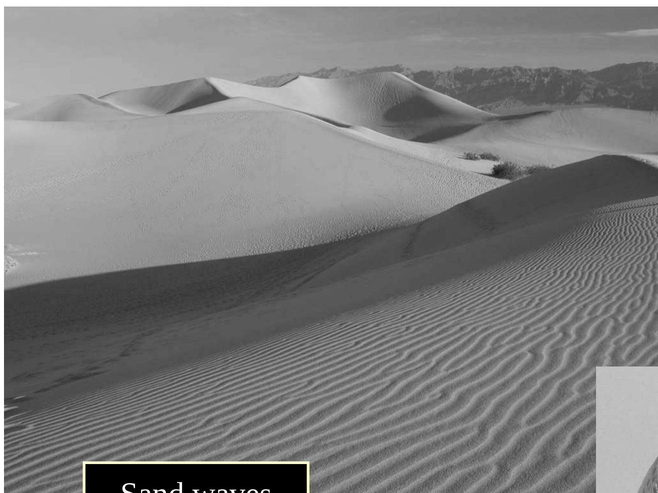
Surface wave

Waves Are Common in Nature


Flag waves


Sound waves


Cloud waves


Sand waves


Slinky waves


Water waves

Overview : What is light?

What Is Light?

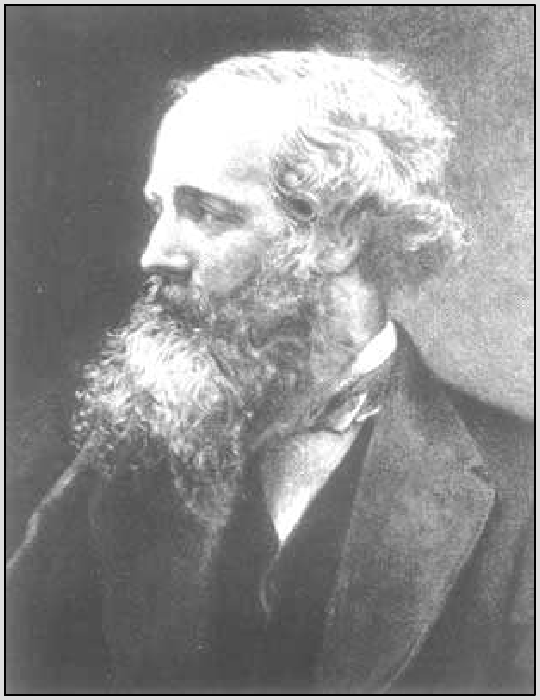
According to Newton (1643 – 1727):

Light is particles, like grains of sand.

What Is Light?

According to Euler (1707 – 1783):

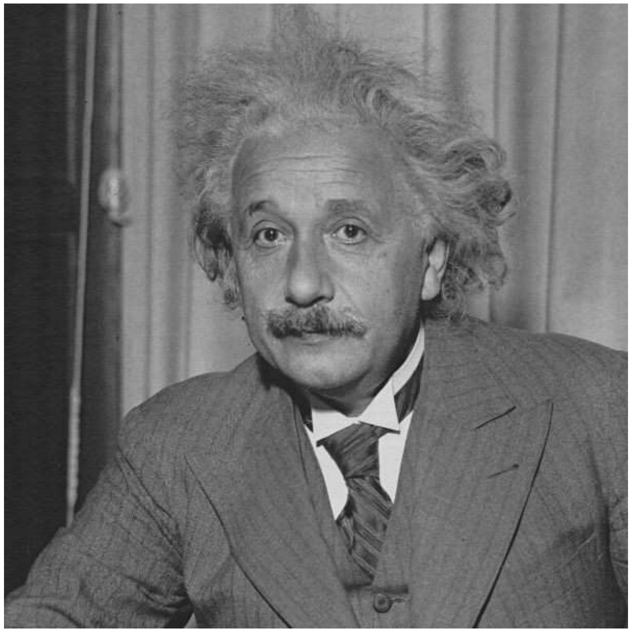
Light is waves, like water or sound waves.



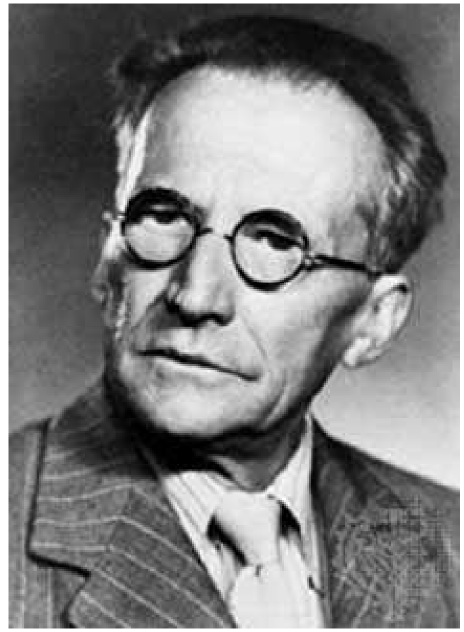
According to Maxwell (1831 – 1879):

Light is waves in electric and magnetic fields – electromagnetic radiation!

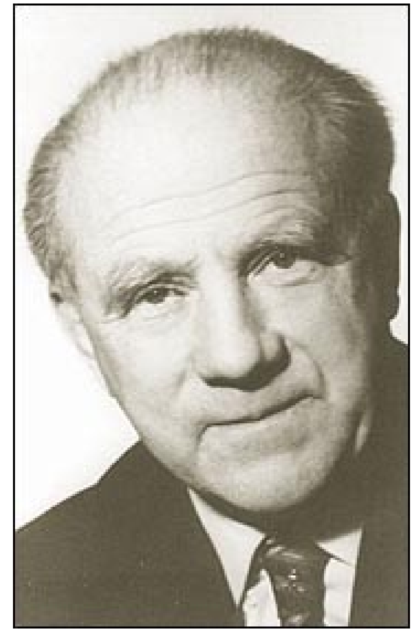
What Is Light?



Einstein
(1879 – 1955)



Schrodinger
(1887 – 1961)



Heisenberg
(1901 – 1976)

Light has a dual nature: It is made up of photons which are packets (quanta) of energy that have both particle and wave properties

In this lecture, we focus on light as electromagnetic waves

Light as electromagnetic waves

Light as waves associated with electric and magnetic fields

James Clerk Maxwell (1831 – 1879) showed that light can be viewed as electromagnetic waves, which are waves associated with vibrating electric and magnetic fields (see Fig. 1 in class)

Maxell's equations

The electrical force and the magnetic force are two aspects of the same force.

Vibrating electric fields are always associated with vibrating magnetic fields.

$$\nabla \cdot \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

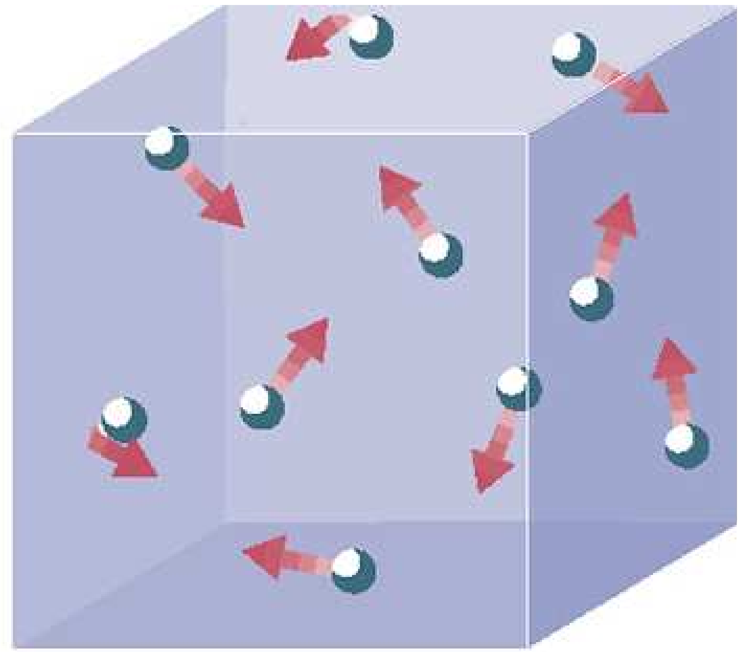
$$\nabla \cdot \mathbf{B} = \frac{1}{c^2}\frac{\partial \mathbf{E}}{\partial t}$$

How does matter emit electromagnetic waves (light)?

Matter is made of atoms, which consist of protons, neutrons and electrons.

Particle	Mass	Electric Charge
Electron	9×10^{-31} kg	negative
Proton	2×10^{-27} kg	positive
Neutron	2×10^{-27} kg	none

<u>How does matter emit electromagnetic waves (light)?</u>



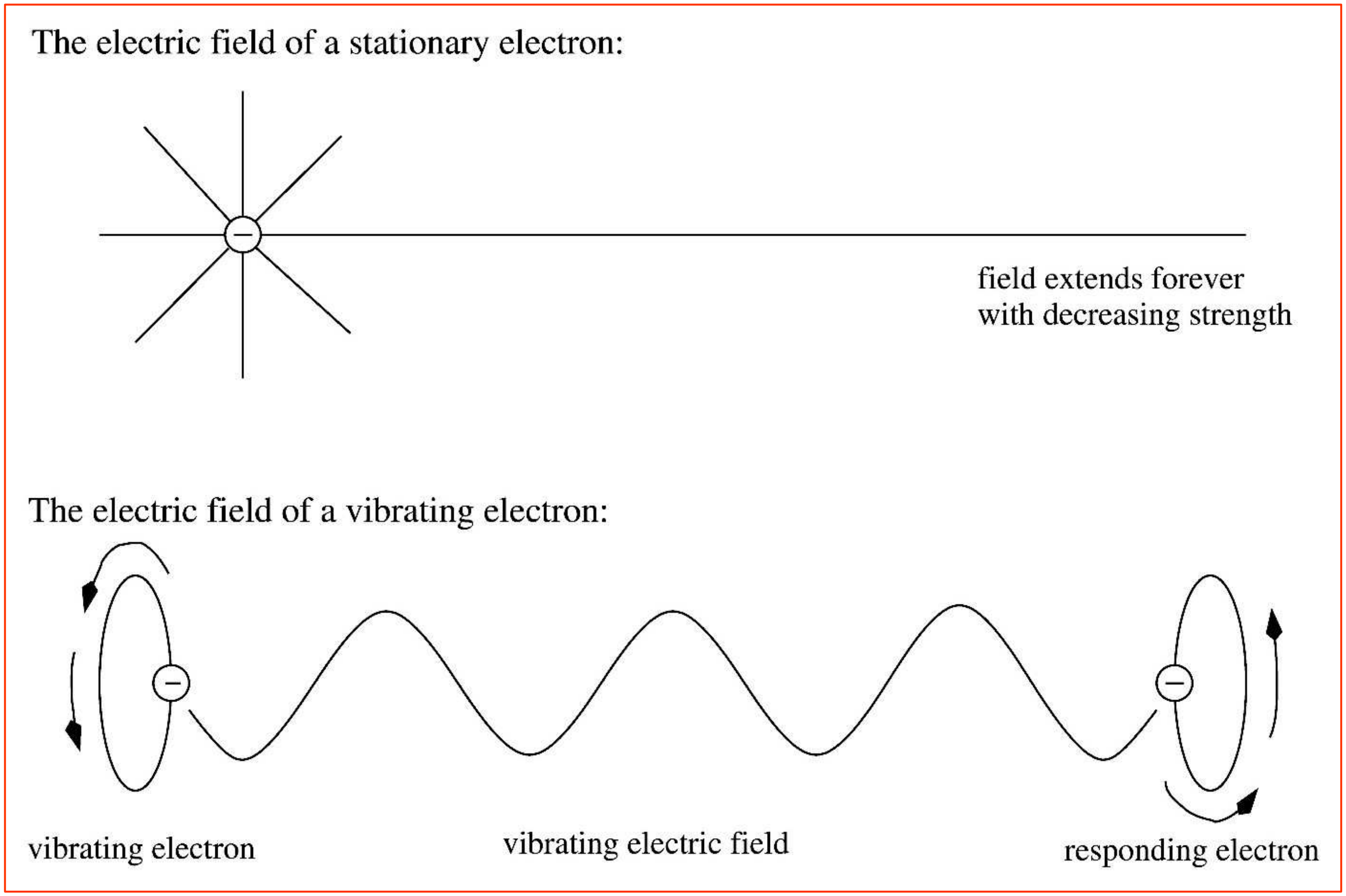
The atoms and hence electrons, protons and neutrons are vibrating in a way set by the temperature of a macroscopic body. (recall thermal energy)

Vibrating electrons cause vibrating electric fields

The vibrating electric fields are associated with vibrating magnetic fields (Maxwell's equations)

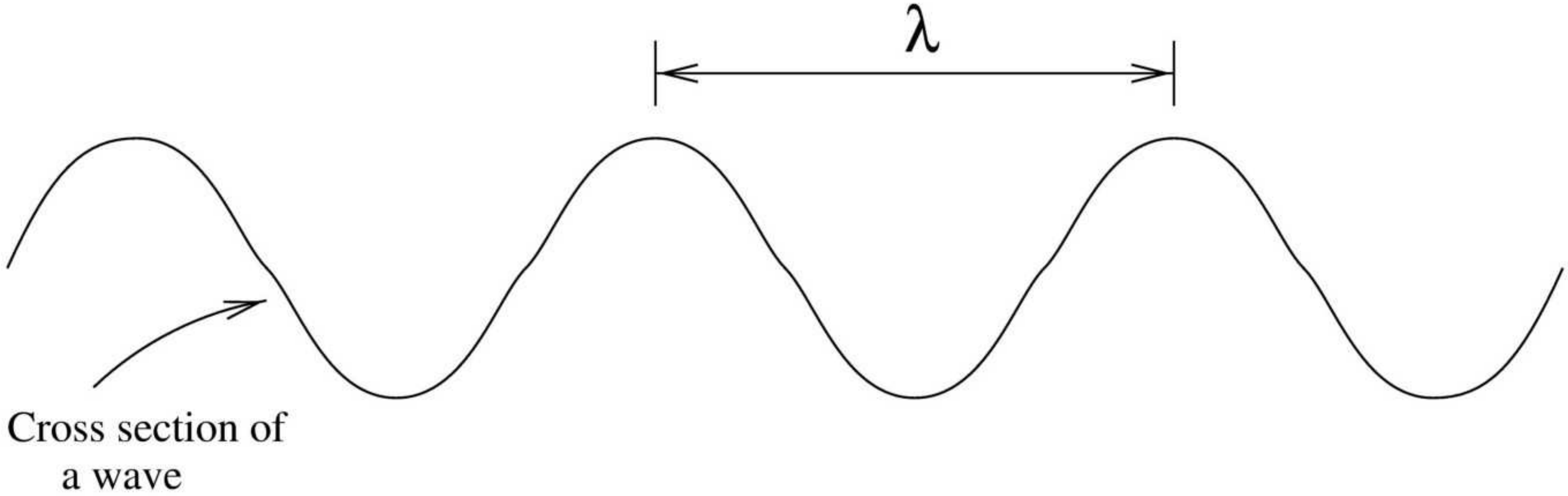
So vibrating electrons produce vibrating electric & magnetic fields, aka light!

How do we 'see' electromagnetic waves (light)?



The vibrating electric field of light cause electrons in the retina to vibrate and to trigger nerve impulses that we perceive as light.

The Wavelength of a Wave

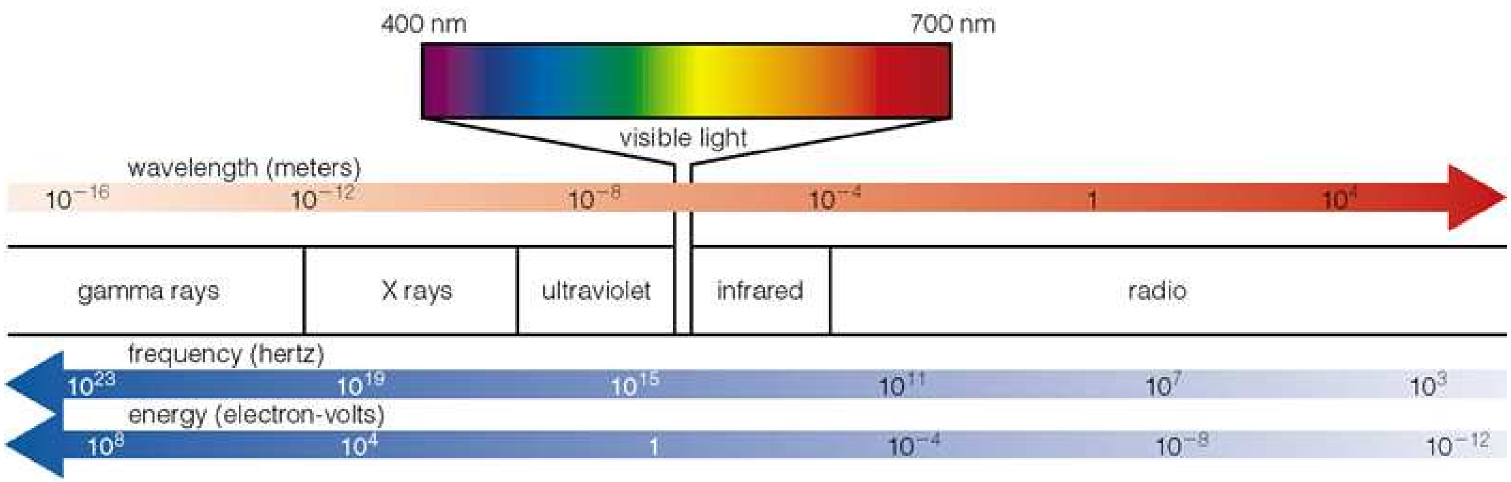


Wavelength is the distance between two peaks of a wave

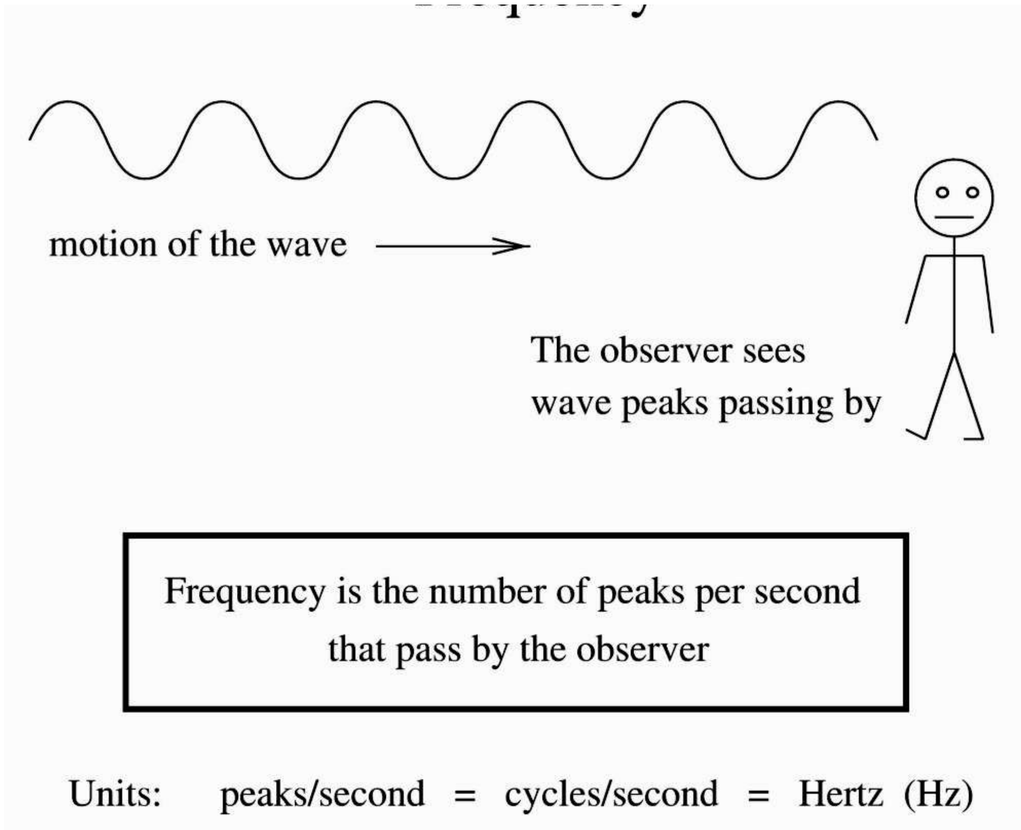
Typical wavelengths	
Water waves	1 m
Sound waves	0.1 m
Light waves	10^{-16} m to 10 m

Wavelength of Electromagnetic Waves or Light

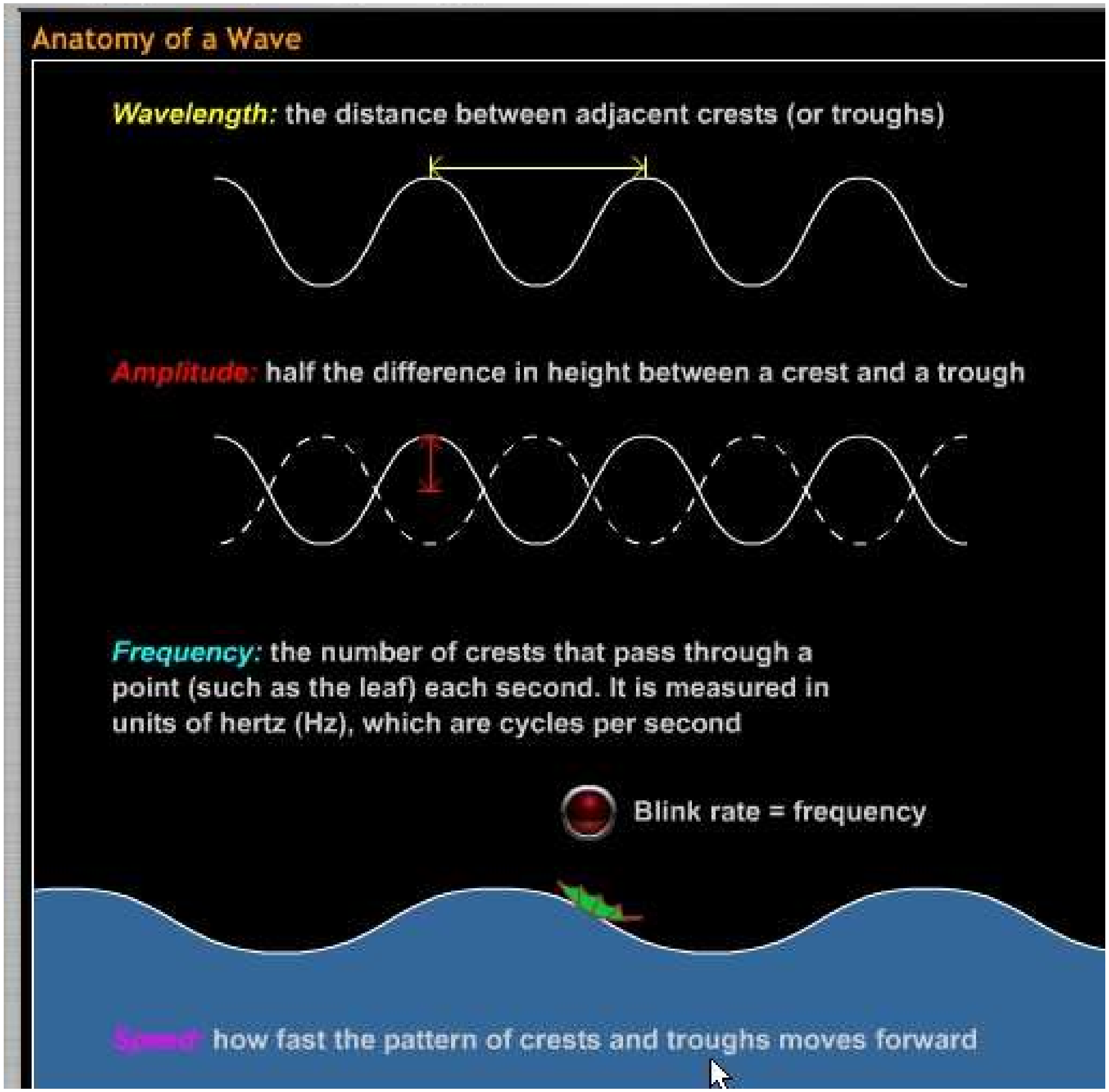
Type of EM wave	TYPICAL WAVELENGTH
Gamma rays	10^{-16} m
X rays	10^{-12} m
Ultraviolet	3×10^{-7} m
Visible	4 to 9×10^{-7} m = Violet, blue, green, yellow, orange, red
Infrared	10^{-6} m to 10^{-4} m
Radio	10^{-3} m to 10 m



The Frequency of a Wave



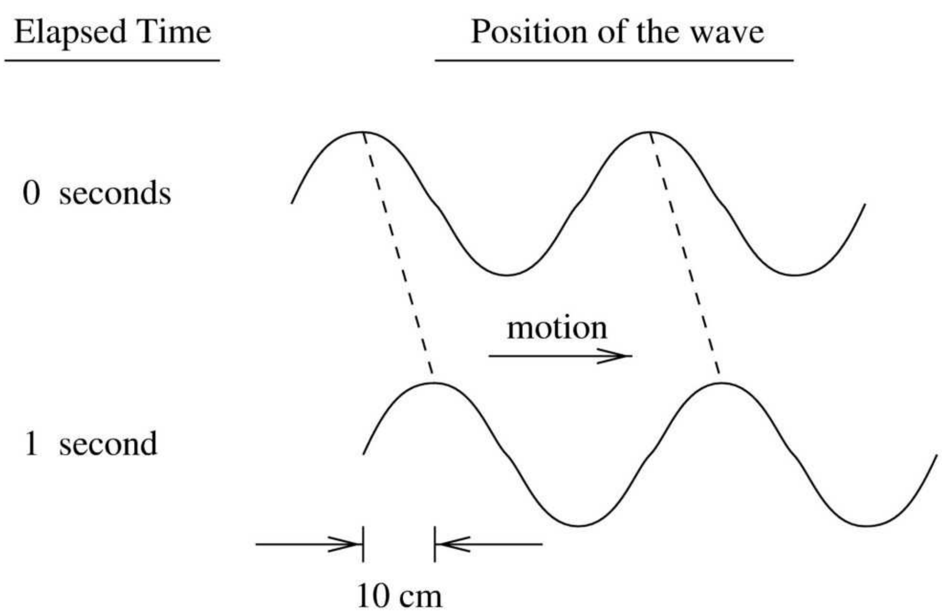
	Typical wavelengths	Typical frequencies
Water waves	1 m	0.1 Hz
Sound waves	0.1 m	440 Hz
Light waves	10^{-16} m to 10 m	3×10^{24} Hz to 3×10^{7} Hz



See In-class animation : wavelength, amplitude, frequency, speed of a wave

The Speed of a Wave

Speed is the rate at which the peaks of a wave move.



$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{10\,\text{cm}}{1\,\text{sec}} = 10\,\text{cm/sec}$$

Typical speeds:

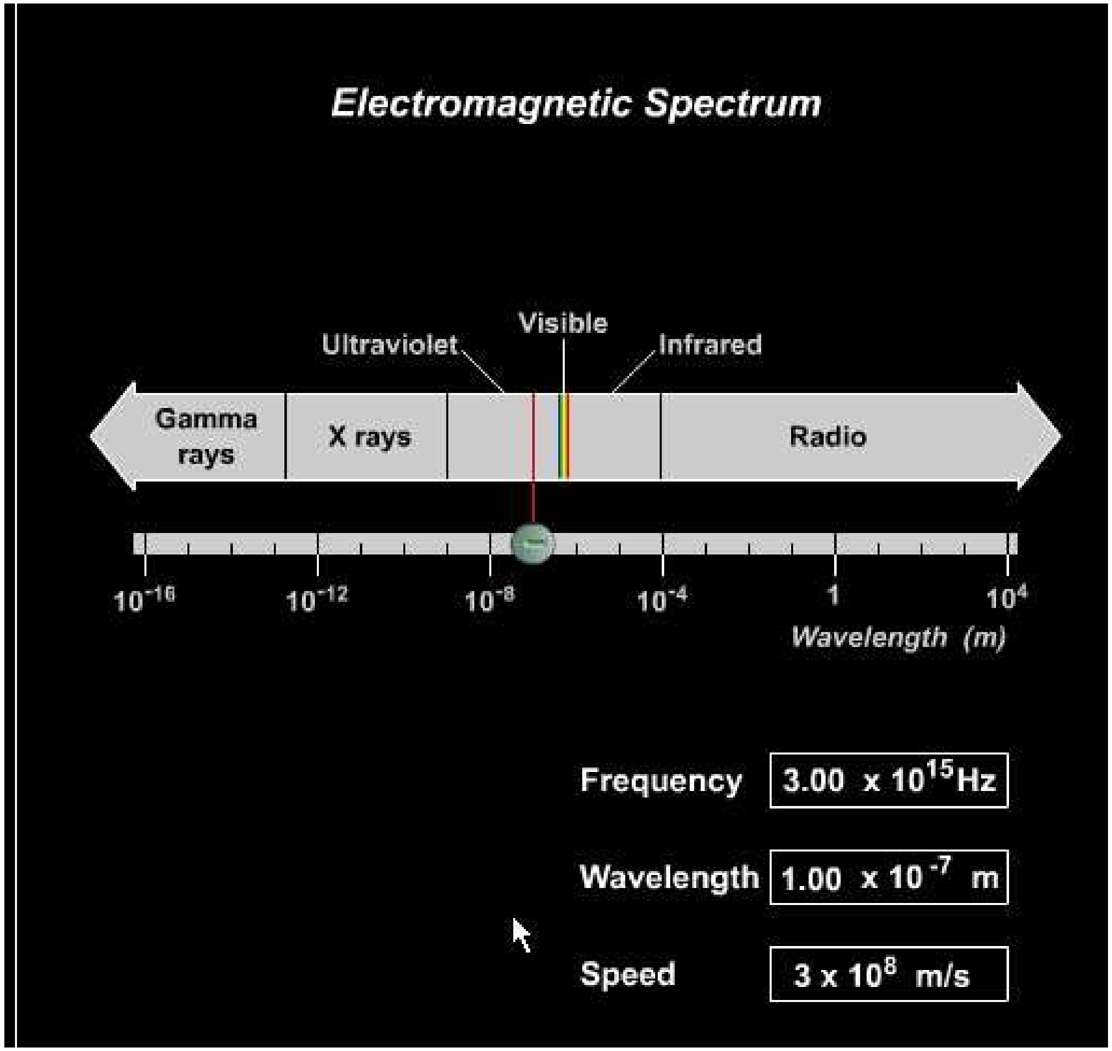
Water: v = 5 meters/sec

Sound: v = 300 meters/sec

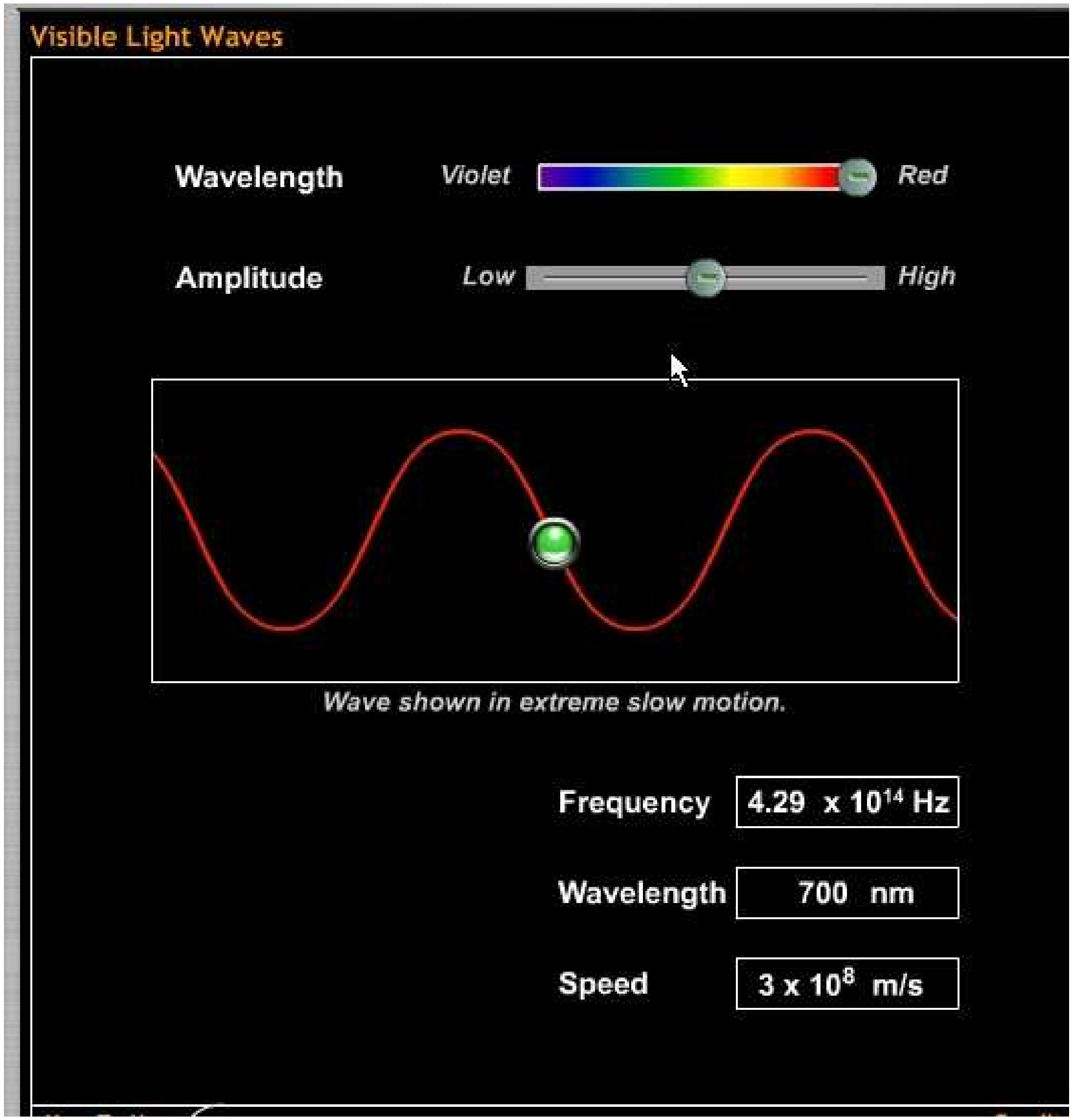
Light: $c = 3 \times 10^8$ m/sec

The Speed of Light Is Special

- The speed of light is $c = 3 \times 10^8$ m/sec.
- Nothing can travel faster than the speed of light.
- The speed of light is constant; it never changes.
- This is basis for the special theory of relativity.



à in-class animation: Speed of Light (Electromagnetic) waves is constant



à in-class animation: Speed of Light (Electromagnetic) waves is constant

The Speed, Frequency, and Wavelength of a Wave Are Related

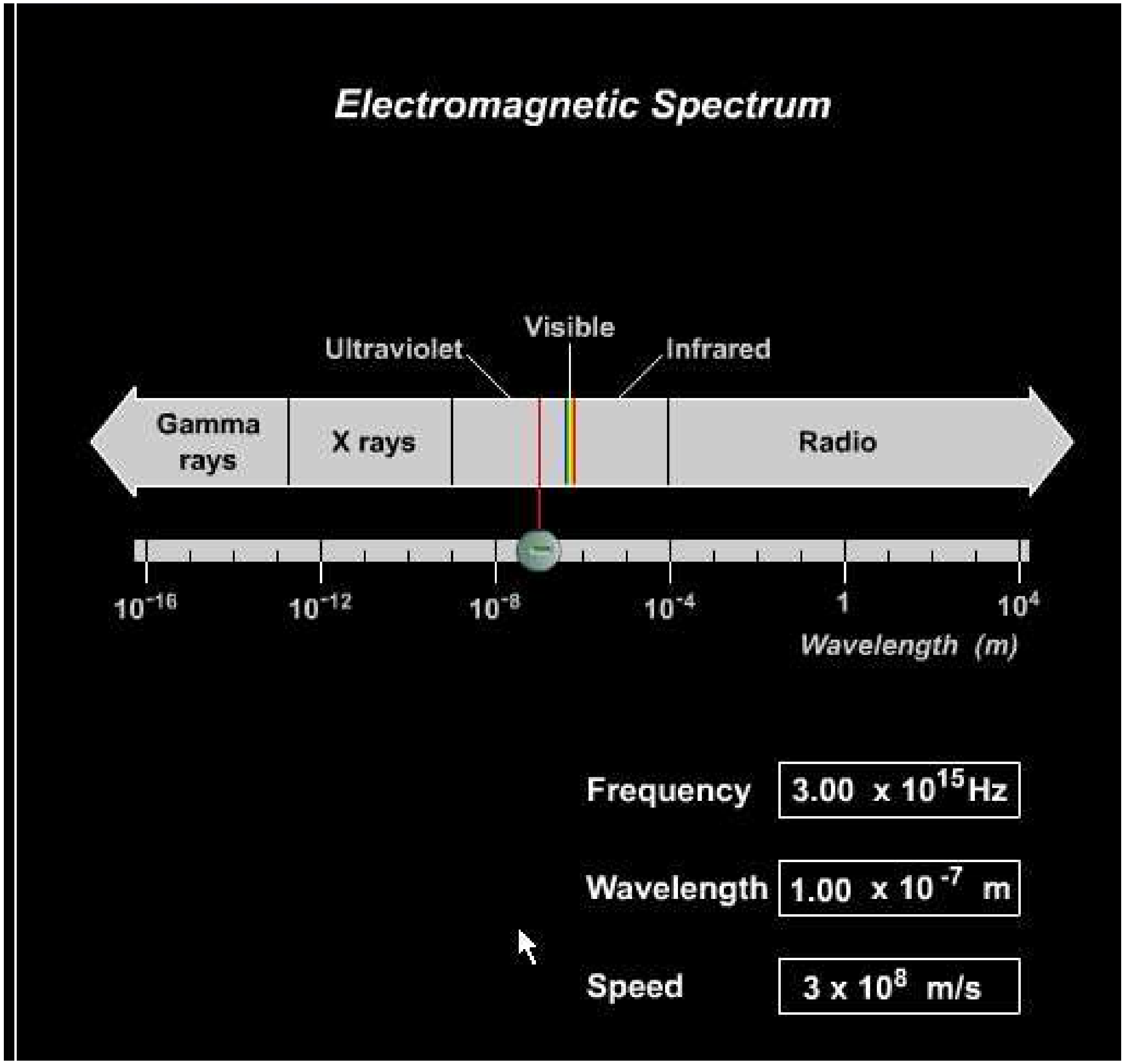
$$(\text{wavelength}) \times (\text{frequency}) = (\text{speed})$$

$$\lambda\nu = c$$

Example: The wavelength of green light is $\lambda = 5.5 \times 10^{-5}$ cm. What is the frequency of green light?

$$\nu = \frac{c}{\lambda} = \frac{3\times10^{10}\ \text{cm/sec}}{5.5\times10^{-5}\ \text{cm}}$$

$$= 5.46\times10^{14}\ \text{Hz}$$



See in-class animation: (wavelength) × (frequency) = (speed)

Derivation of the Equation $\lambda\nu = c$

- The distance traveled by light in time *t* is:

$$distance = speed \times time$$
$$d = ct$$

- The number of wavelengths in that distance is:

$$number\ of\ wavelengths = \frac{distance}{one\ wavelength}$$
$$N = \frac{d}{\lambda}$$
$$N = \frac{ct}{\lambda}$$

- Frequency is the number of wavelengths per second:

$$frequency = \frac{number\ of\ wavelengths}{time}$$
$$\nu = \frac{N}{t} = \frac{ct/\lambda}{t}$$
$$\nu = \frac{c}{\lambda}$$

Energy Carried by a Wave is set by its Amplitude

1) A wave carries energy

Example: Light carries the energy of the sun through space from the sun to the Earth. The Earth receives 1370 Watts per square meter from the sun, enough to power thirteen 100 Watt light bulbs or one toaster oven.

2) The energy carried by a wave depends on its amplitude A.

3) In the wave model of light, the energy carried by lights waves depends on the amplitude and not on the wavelength of the light

This is a very important difference compared to the photon model of light where the energy depends on the wavelength or frequency of the photon