Physics 1230: Light and Color

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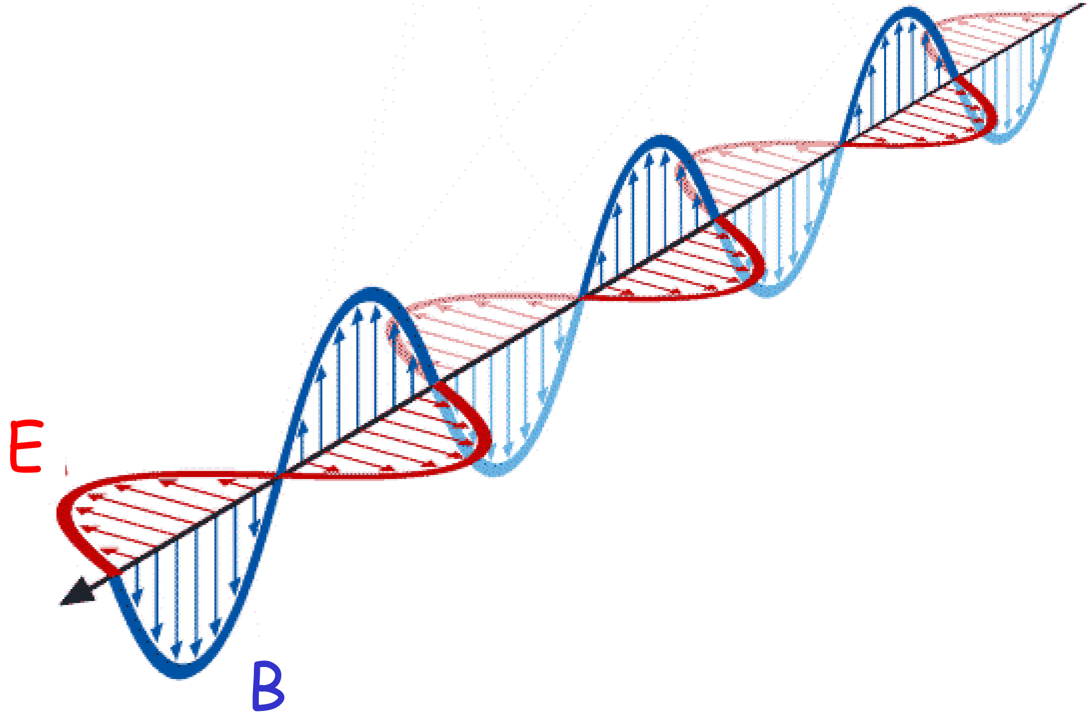
Lecture 2:
Electric and magnetic fields and LIGHT

HW2 on CULearn: DUE ON THURSDAY, 5PM.

Today

- Electric fields
- Magnetic fields
- Light is an ‘electromagnetic wave’



Fire up the iClickers

- Swap clicker code to DC

- Hold down On/Off Switch 4 seconds
- Flashing blue light: hit **D C**

- Should see GREEN light and you're ready to go.

Last Time: QUALITATIVE things about electric forces.

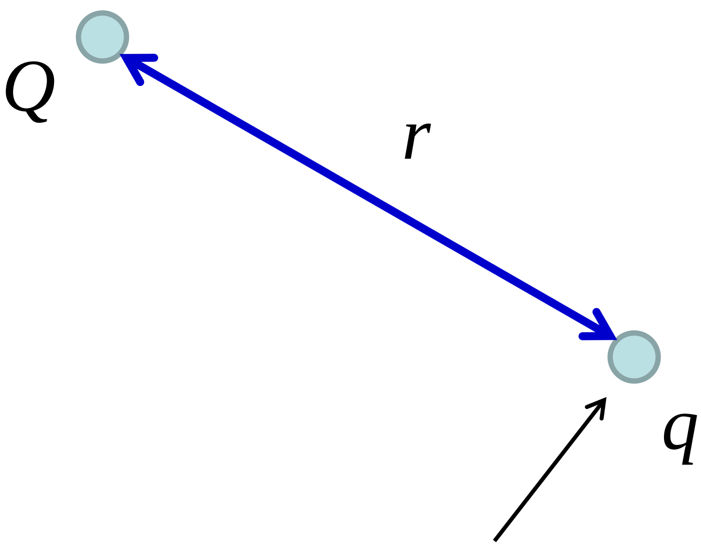
A) There are two types of charge
B) There is only one type of charge
C) There are more than two types
D) None of the above.

A) Like charges attract
B) Like charges repel
C) Opposite types repel
D) Depends on the situation.

And opposites attract

QUANTITATIVE statement:

<u>Coulomb's Force Law</u>:



What is the force that q feels from Q?

Depends on the charges

$$F_{qQ} = k\,\frac{qQ}{r^2}$$

Constant of nature.

distance

A question:

You are given three numbers, *a*, *b*, and *c*.
True or false: The combination of numbers

$$\frac{ab}{c} \quad \text{is always equal to:} \quad a\frac{b}{c}$$

A) TRUE

B) FALSE

Experiment: Try some actual numbers, like *a=2, b=3, c=4* and test it.

You are given <u>four</u> numbers, *a*, *b*, *c*, and *d*. Which of these are valid ways to rewrite $\dfrac{ab}{cd}$

A) $a\dfrac{b}{cd}$

B) $b\dfrac{1}{cd}a$

C) $\left(\dfrac{1}{c}\right)\left(\dfrac{ab}{d}\right)$

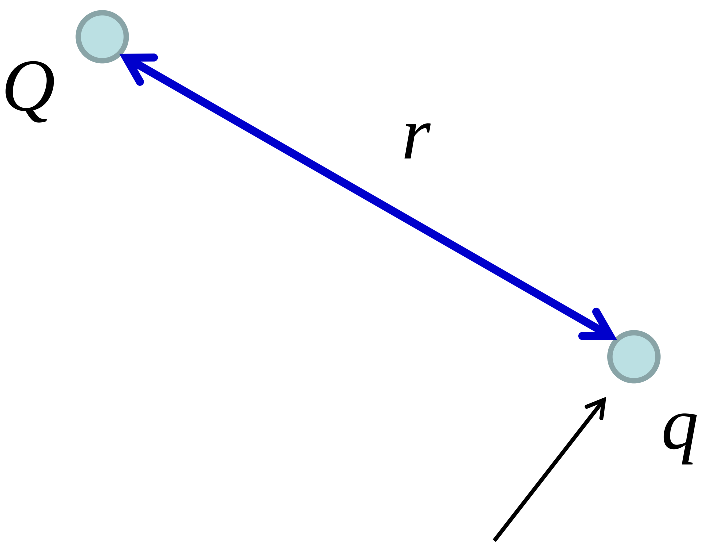
D) All of the above

E) None of the above

Experiment can be valuable here too…

QUANTITATIVE statement:

Coulomb's Force Law:



What is the force that q feels from Q?

Depends on the charges

$$F_{qQ} = k\frac{qQ}{r^2}$$

Constant of nature.

distance

Useful to rewrite things:

Coulomb's Force Law:

$$F_{qQ} = k\frac{qQ}{r^2}$$

Which is another way to write this force law?

A) $F_{qQ} = k\frac{q+Q}{r^2}$

B) $F_{qQ} = \frac{q}{r^2}k\frac{Q}{r^2}$

C) $F_{qQ} = q\left(k\frac{Q}{r^2}\right)$

D) None of these

E) All of these

The universe divides into two parts:

Coulomb's Force Law:

$$F_{qQ} = q\left(k\frac{Q}{r^2}\right)$$

Property of the local THING, say YOU.

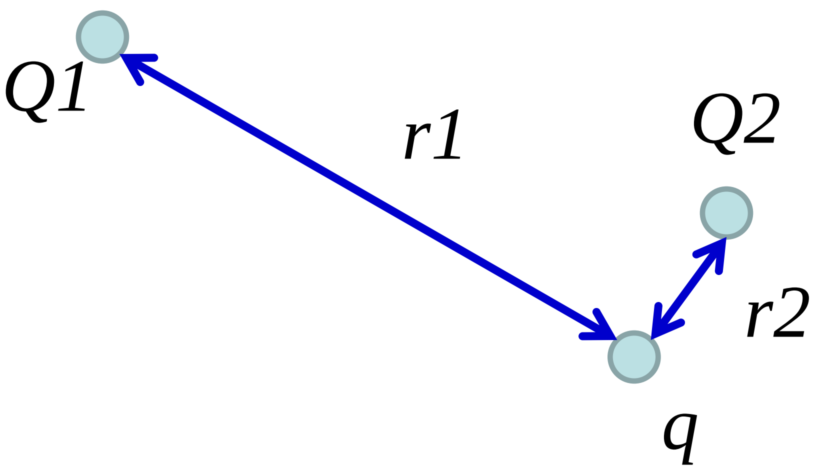
Properties of the rest of the universe.

We Say: $F_q(r) = qE$

ELECTRIC FIELD due to the rest of the universe.

Suppose we have 3 charges:

<u>The force felt by q ...</u>



A) Can still be $F=qE$
B) Cannot be $F=qE$
C) MAY be $F=qE$ if the charges are in a line.
D) Something else happens.

$$F_{qQ} = k\frac{qQ1}{r1^2} + k\frac{qQ2}{r2^2} = q\left(k\frac{Q1}{r1^2} + k\frac{Q2}{r2^2}\right) = qE$$

Electric Fields

We Say that charges feel a force:

ELECTRIC FIELD due to the rest of the universe.

$$F_q(r) = qE$$

The charge value.

Properties of the rest of the universe.

What do you already know about magnetism?

A) Magnets come with only a north pole
B) Magnets come with only a south pole
C) Magnets come with both a north and south pole.
D) Depends upon the type of magnet.

A) Like poles attract
B) Like poles repel
C) Opposite poles repel
D) Depends on the situation.

<u>GUESS WHAT</u>: The universe produces Magnetic Fields too.

Two separate topics?

Electricity

Magnetism

For many years, people thought they were essentially unrelated.

World changing observations(1):

Oersted (1821) found that moving charges create magnets.

AND

Moving charges feel forces from magnets.

Electric and magnetic fields

Electromagnetic, or Lorentz, forces

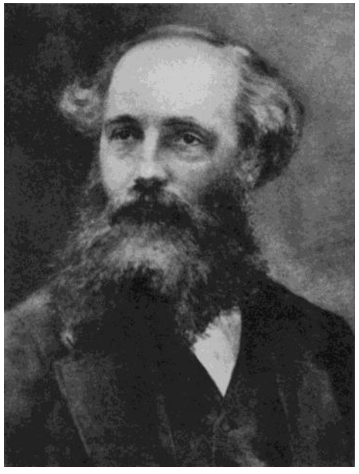
Forces on charges arise from particle properties and properties of the rest of the universe:

Properties of the particle

$$\vec{F}_q = q\left(\vec{E} + \vec{v} \times \vec{B}\right)$$

Properties from the rest of the universe.

World changing observations(2):



Maxwell (1861) found that changing electric fields create magnetic fields.

AND

Changing magnetic fields create electric fields (Faraday).

Electric and magnetic fields can create each other, EVEN WITHOUT Charges!

Hero worship:

“From the long view of the history of mankind – seen from, say, ten thousand years from now – there can be little doubt that the most significant event of the 19th century will be judged as Maxwell’s discovery of the laws of electrodynamics. The American Civil War will pale into provincial insignificance in comparison with this important scientific event of the same decade.”

Richard P. Feynman,

Lectures on Physics, Vol. 2, 1-11

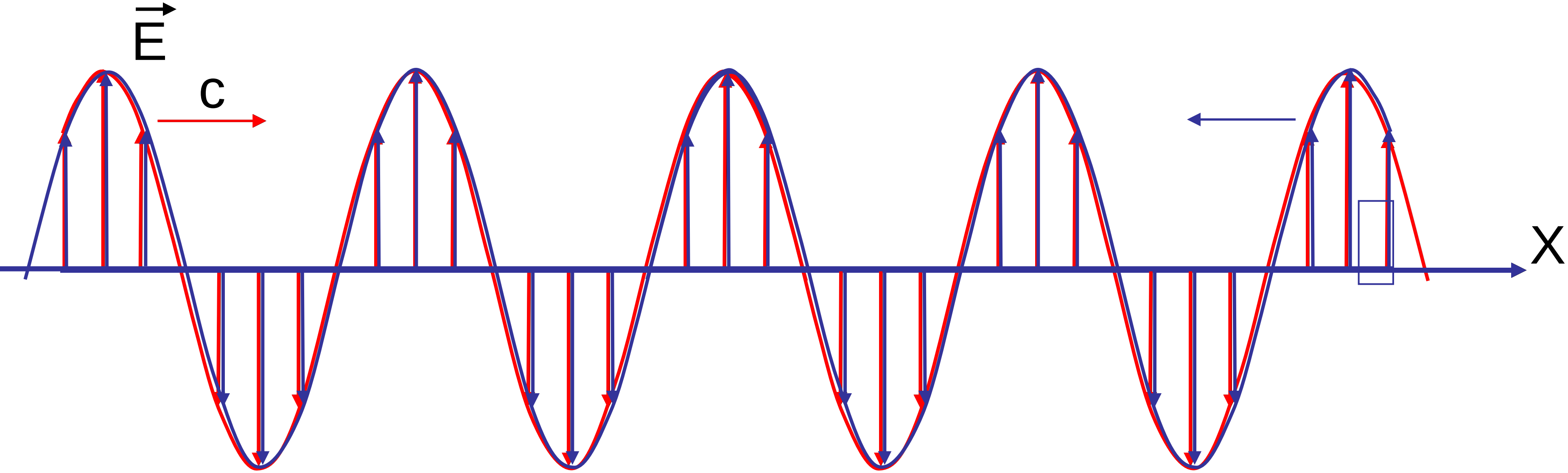
Light is an oscillating E and B-field

- Oscillating ELECTRIC and magnetic field
- Traveling to the right at speed of light (c)

Electromagnetic radiation

Snap shot of E-field in time:

At t=0 A little later in time



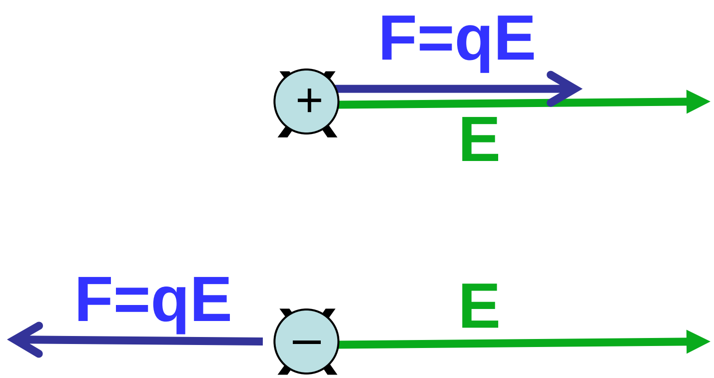
Function of position (x) and time (t):

$$E(x,t) = E_{max}\sin(ax+bt)$$

Properties of light → Interaction with matter

Electric fields exert forces on charges

(e's and p's in atom)



Force = charge x electric field

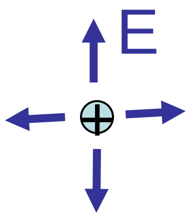
$\vec{F} = q\vec{E}$

Light is an oscillating E-field (and B-field). It interacts with matter by exerting forces on the charges – the electrons and protons in atoms.

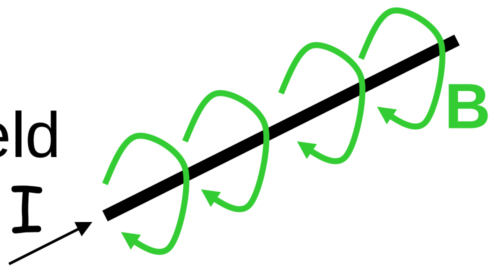
How do you generate light (electromagnetic radiation)?

a. Stationary charges
b. Charges moving at a constant velocity
c. Accelerating charges
d. b and c
e. a, b, and c

Stationary charges →
constant E-field, no magnetic (B)-field



Charges moving at a constant velocity →
Constant current through wire creates a B-field
But B-field is constant



Accelerating charges →
changing E-field and changing B-field
(EM radiation → <u>both E and B are oscillating</u>)

How do you generate light (electromagnetic radiation)?

a. Stationary charges

b. Charges moving at a constant velocity

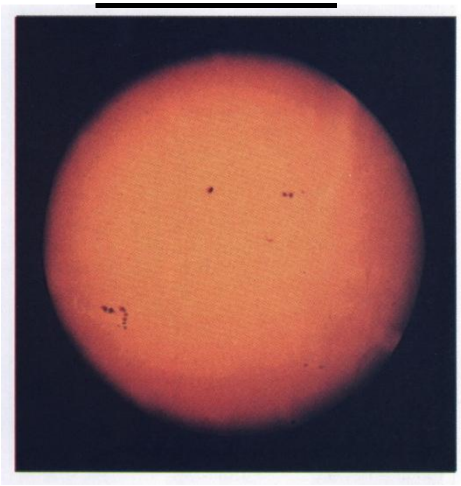
c. Accelerating charges

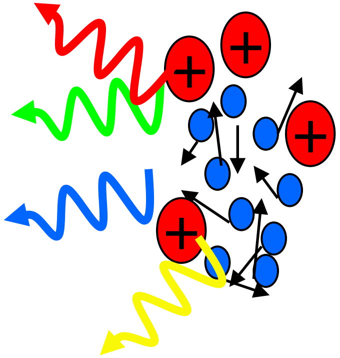
d. b and c

e. a, b, and c

Ans. is c. *Accelerating* charges create EM radiation.

The Sun





Surface of sun- very hot!
Whole bunch of free electrons whizzing around like crazy.
Equal number of protons, but heavier so moving slower, less EM waves generated.

Go to radiowave sim

Sources of Light in Nature

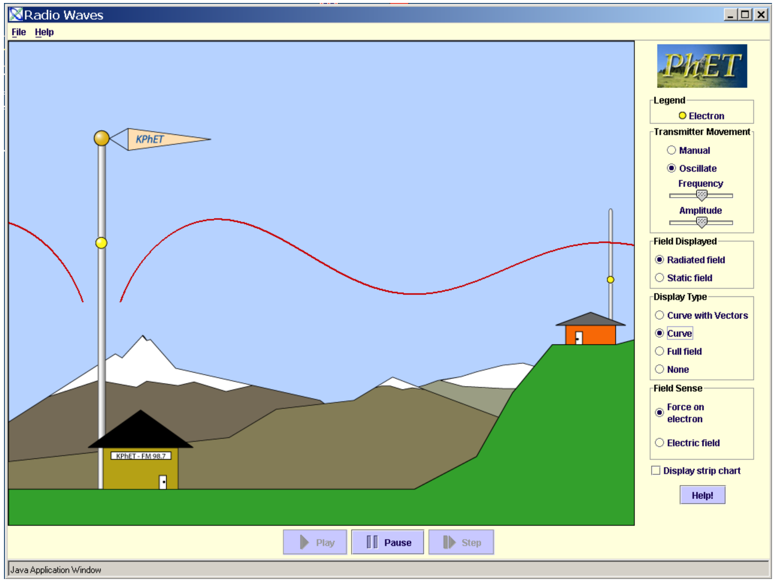
Sources of Light in Nature

NOTICE:

Some things are ‘self-luminous’, like the SUN. They burn energy and release light.

Some things are NOT self-luminous. Their charges are forced to wiggle by light from other things. The MOON

EM radiation often represented by a sinusoidal curve.



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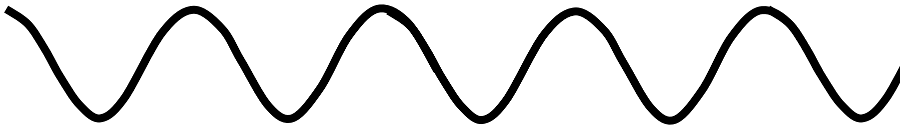
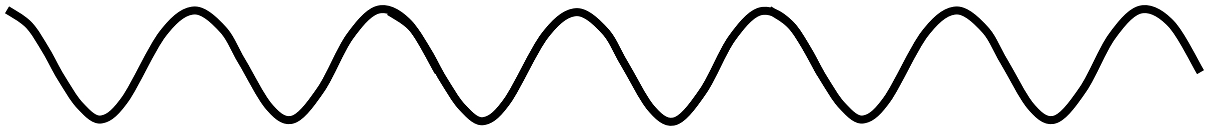
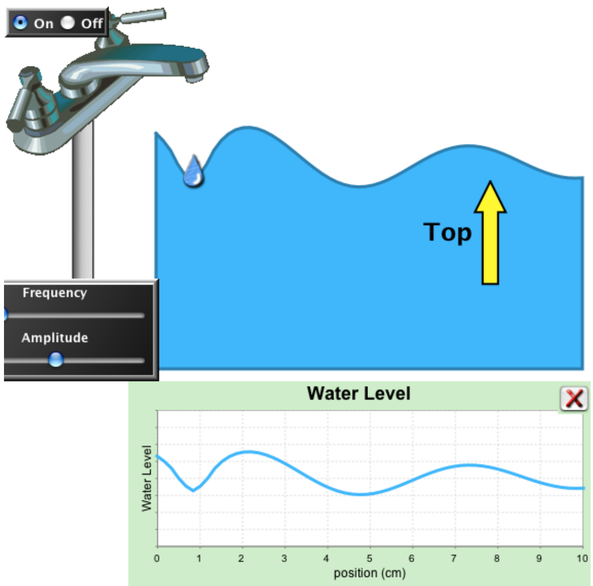
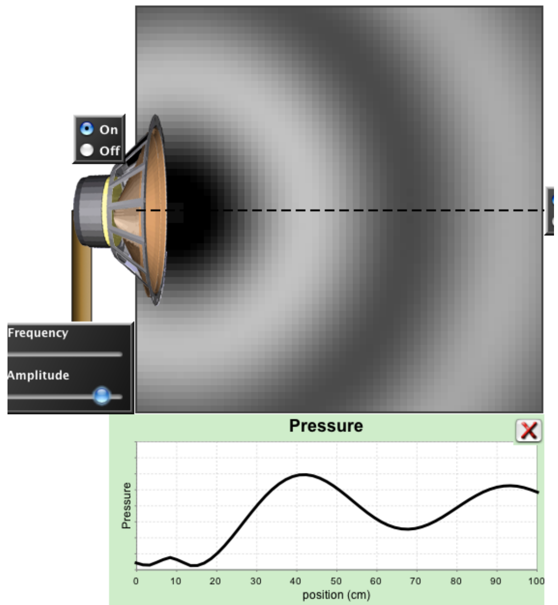


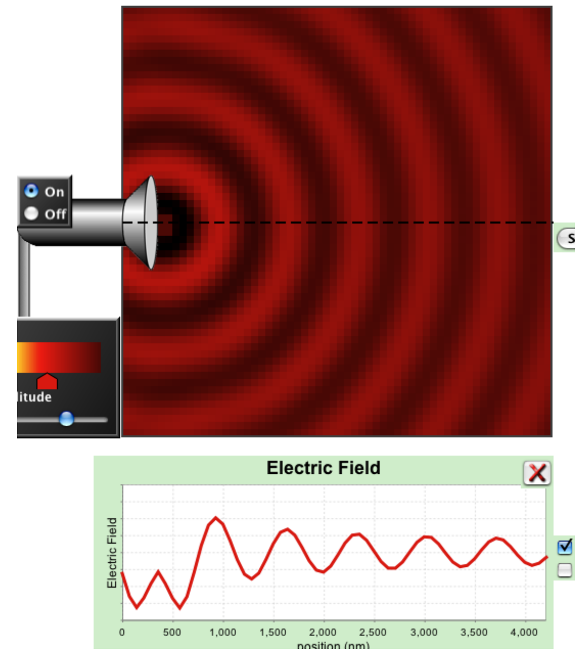
a. The spatial extent of the E-field. At the peaks and troughs the E-field is covering a larger extent in space
b. The E-field's direction and strength along the center line of the curve
c. The actual path of the light travels
d. more than one of these
e. none of these.

Making sense of the Sine Wave







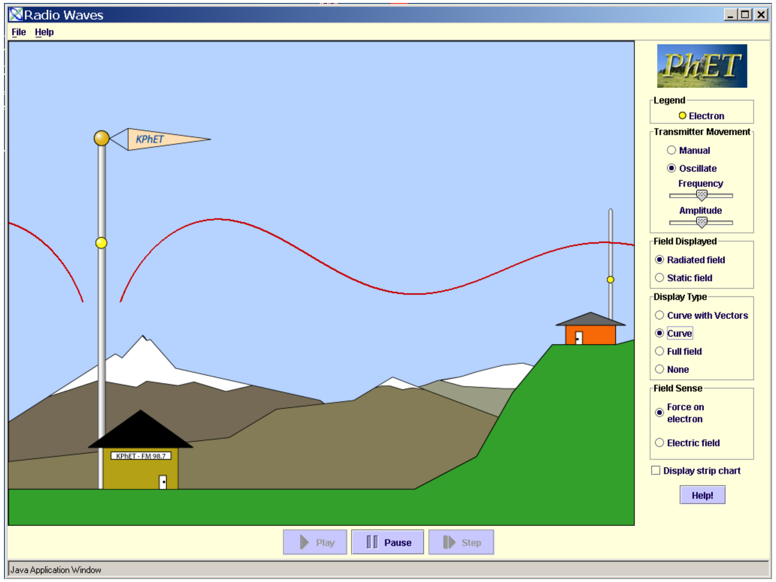


- -For Water Waves?
- -For Sound Wave?
- -For E/M Waves?

Made it to here, Lecture 2.

- Phet radio sim drew lots of questions
- People wanted to know: How do you send information (we talked about AM and FM)
- Radiation in all directions was noticed.
- Water and Sound waves drew lots of ‘Ahah’ type responses.

EM radiation often represented by a sinusoidal curve.



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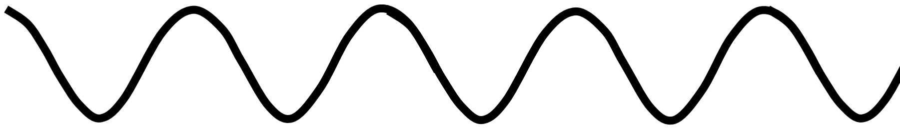
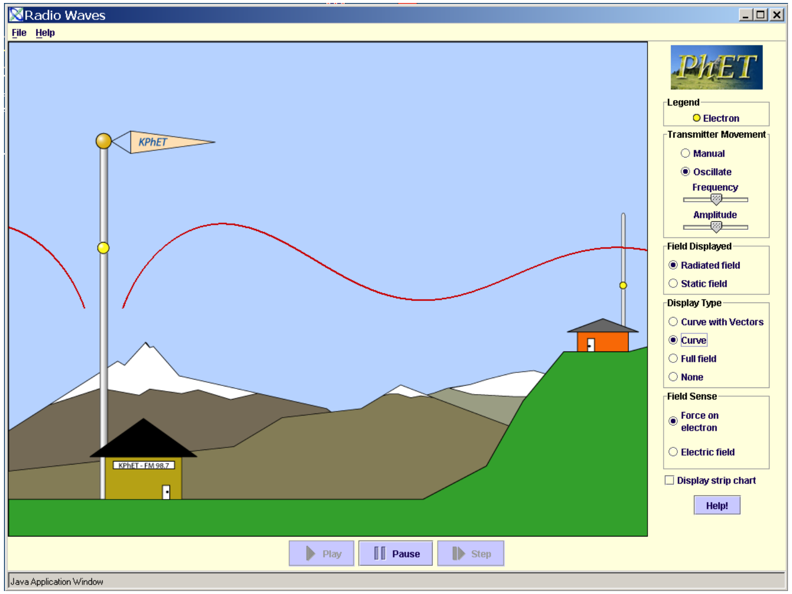


a. The spatial extent of the E-field. At the peaks and troughs the E-field is covering a larger extent in space
b. The E-field's direction and strength along the center line of the curve
c. The actual path of the light travels
d. more than one of these
e. none of these.

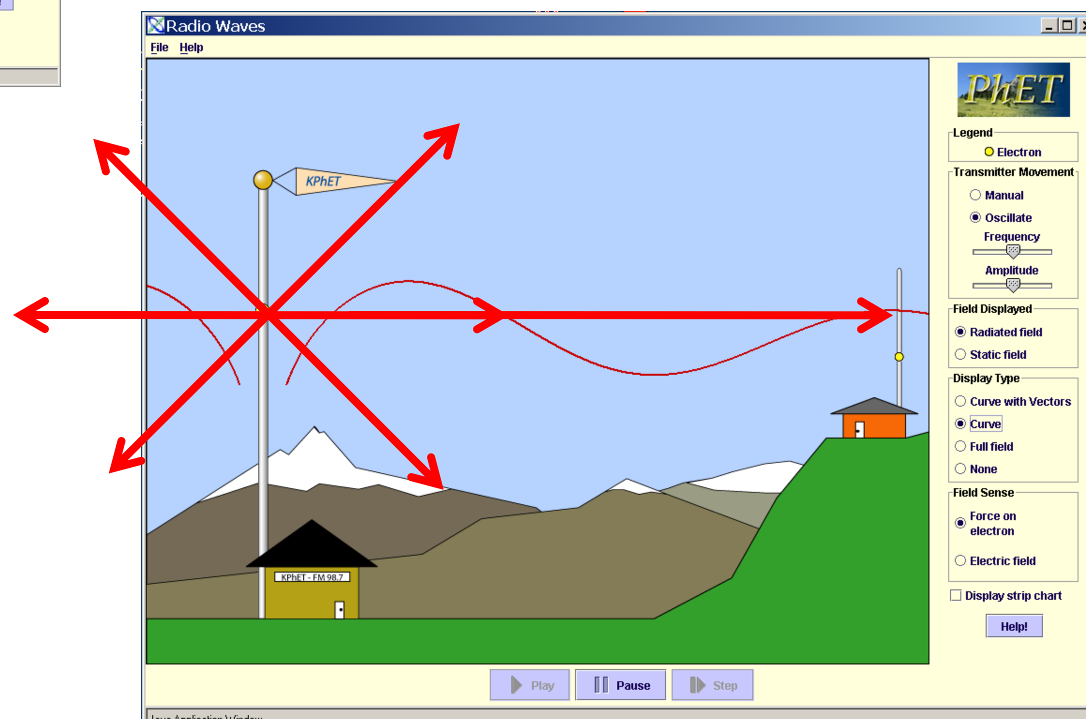
Our first simplification: Light Rays.



1. Concentrate on the directions of light travel. Straight lines.
2. Only the light that reaches the observer causes a response.

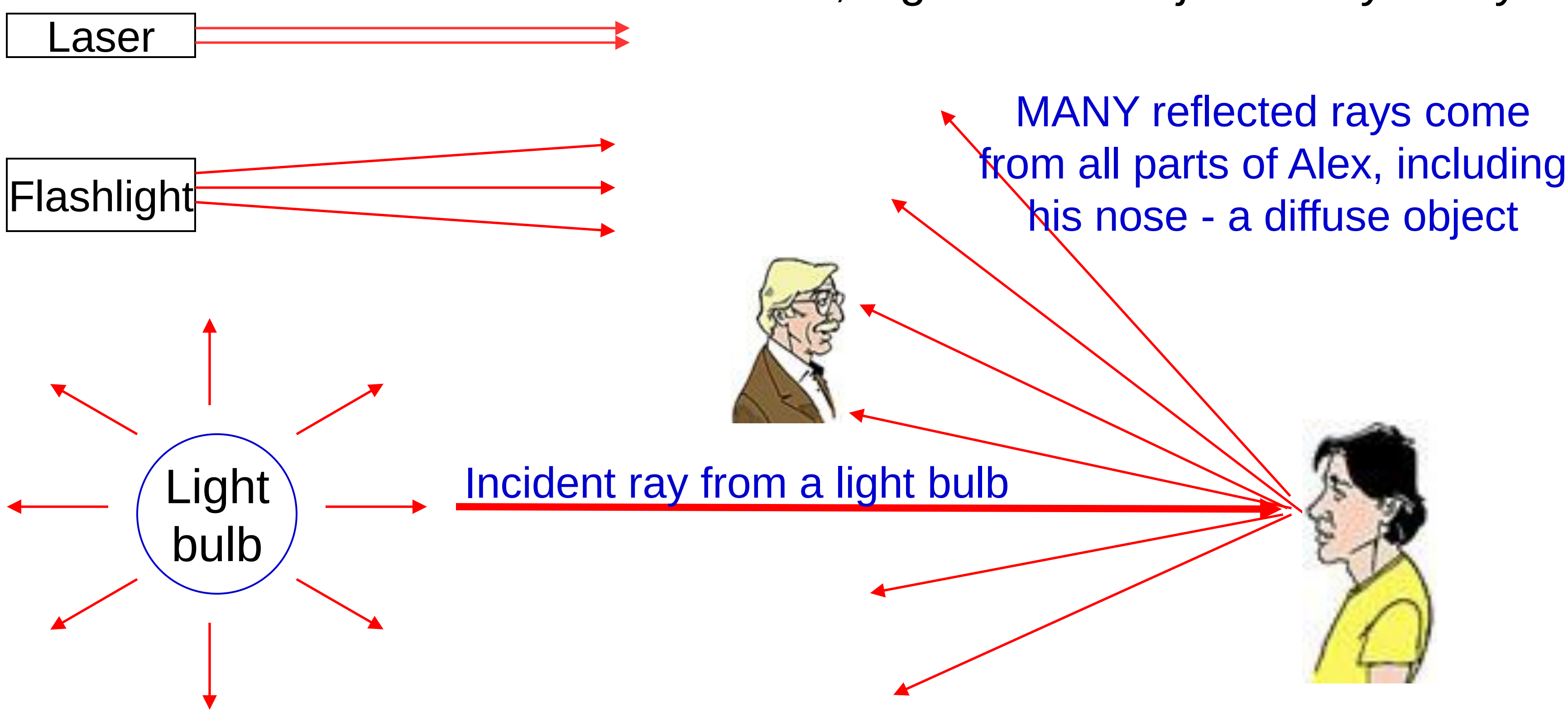
OR

Light Rays!



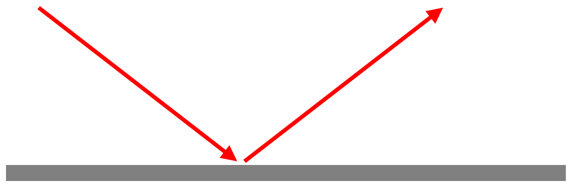
Seeing everything in terms of rays

Light rays are invisible unless they enter directly into our eye or are scattered by smoke, fog or some *object* into your eye!



Bob sees Alex's nose because a reflected light ray enters Bob's eye

Rays bounce when they reflect off a mirror or shiny surface



This is called specular reflection.

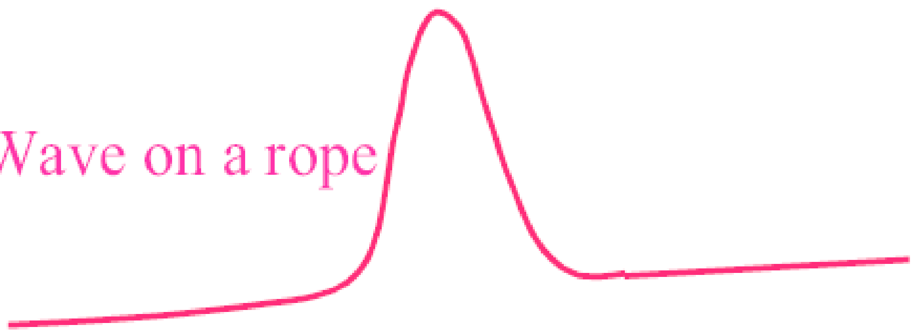
- How is it different from diffuse reflection?

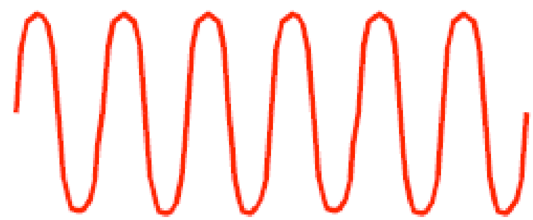
More about Waves

• A wave is a propagating *disturbance* of some equilibrium state - for example wave on water, waves on a rope, light in vacuum etc.

• The *medium* does not have to move far - but the *disturbance* moves, often at some characteristic speed (e.g. cork on water)

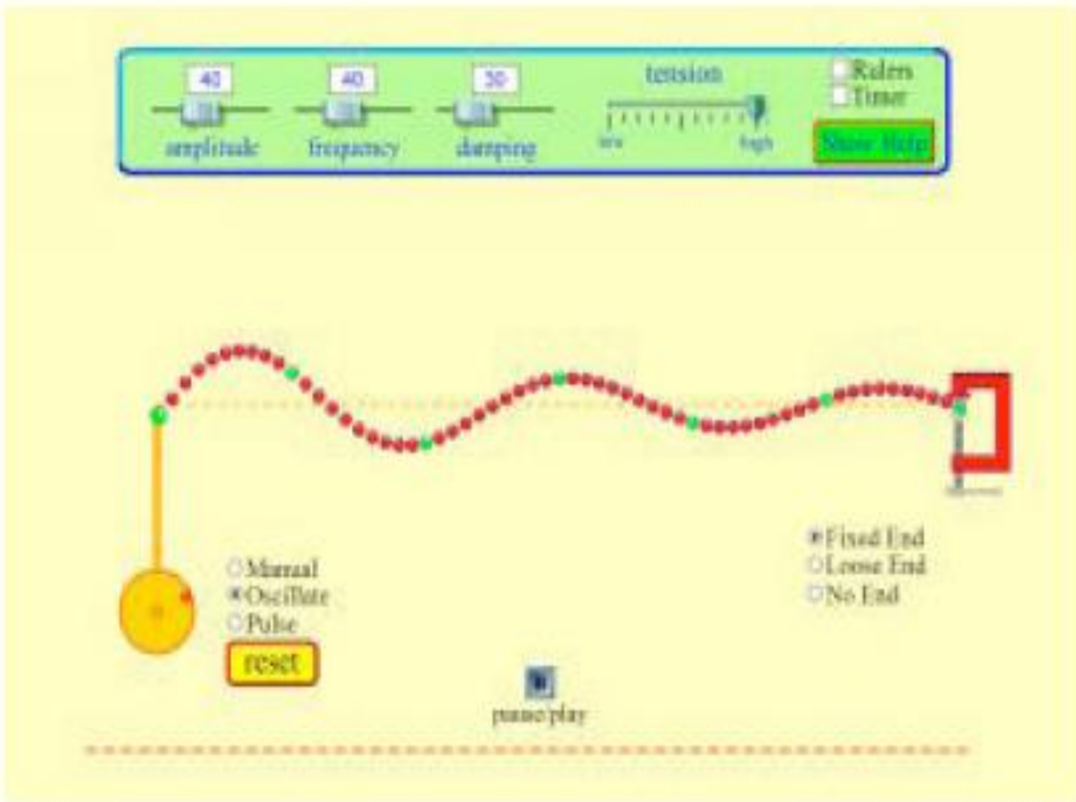
Wave on a rope





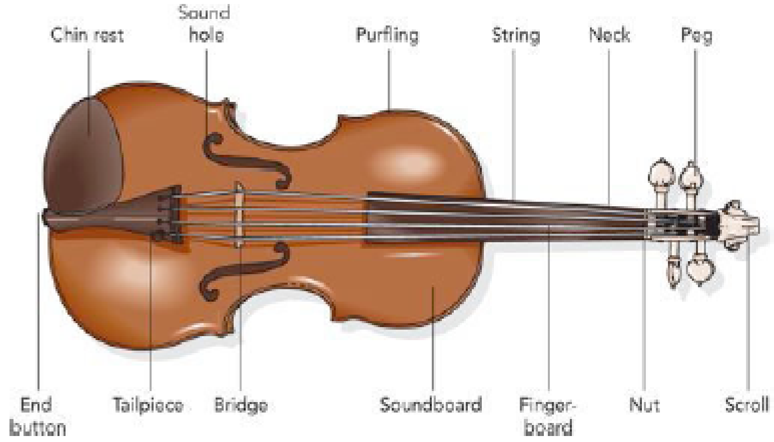
Light waves

Waves on a Rope



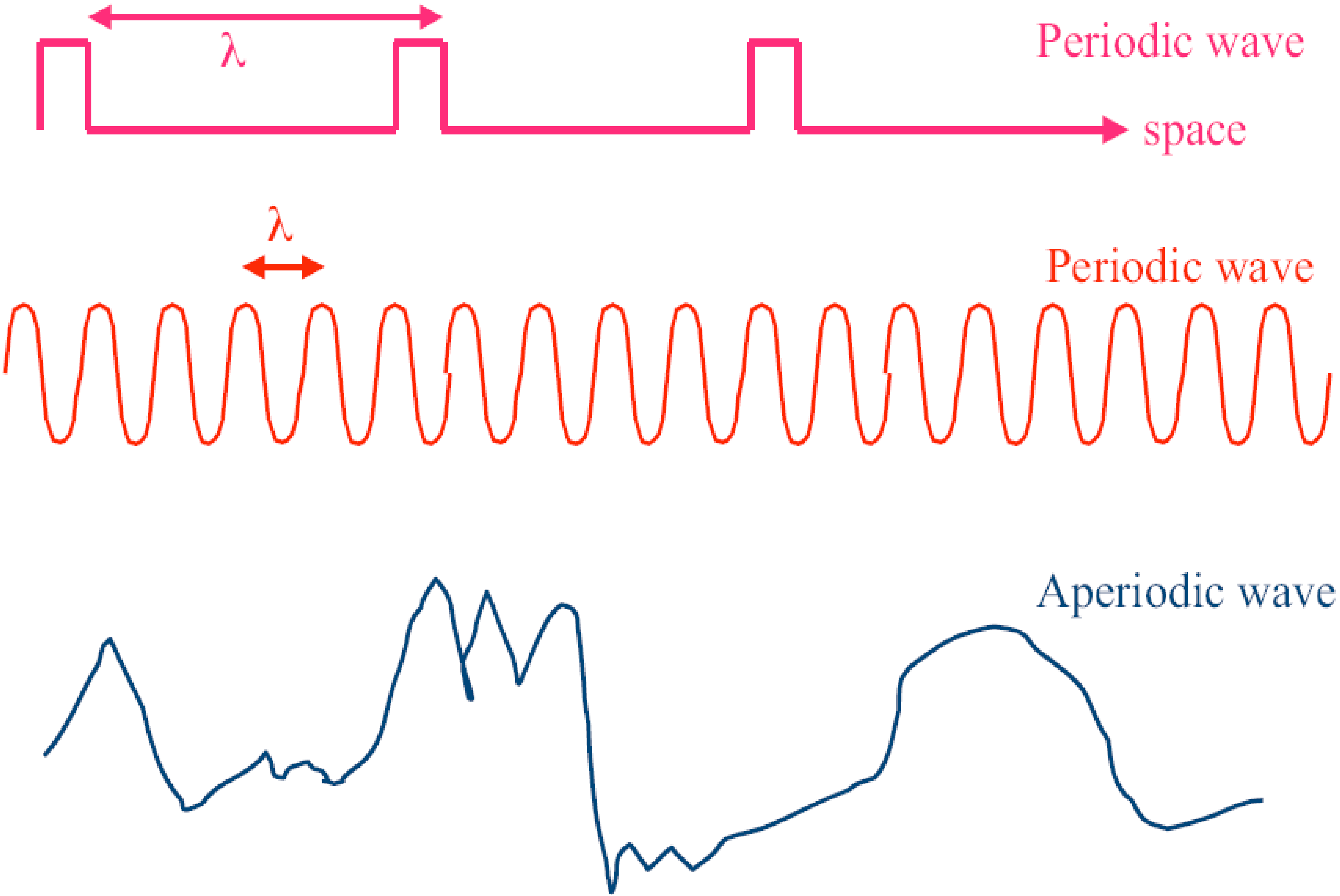
http://phet.colorado.edu/sims/string-wave/string-wave_en.html

Sound Waves



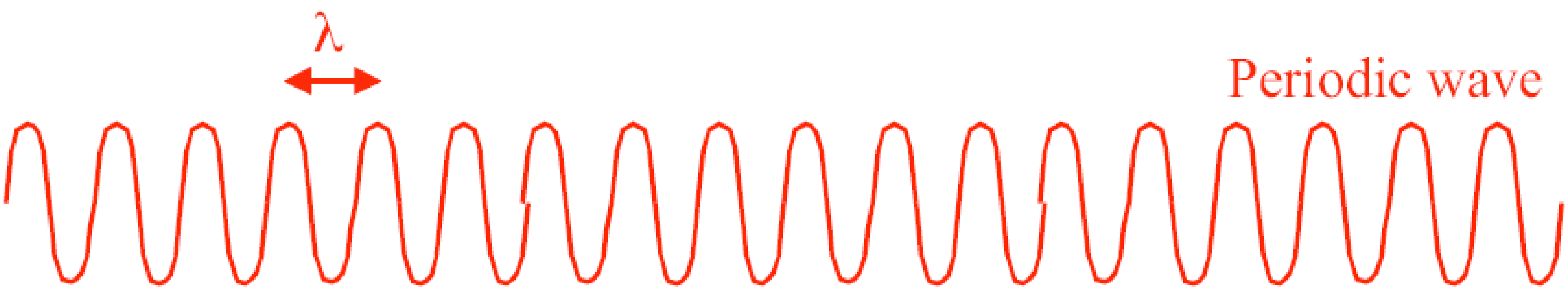
Sound is also a type of wave that we cannot see. Like ocean waves, sound waves need a medium to travel through. Sound can travel through air because air is made of molecules. These molecules carry the sound waves by bumping into each other, like Dominoes knocking each other over. Sound can travel through anything made of molecules - even water! There is no sound in space because there are no molecules there to transmit the sound waves!

Waves can be either Periodic or Aperiodic



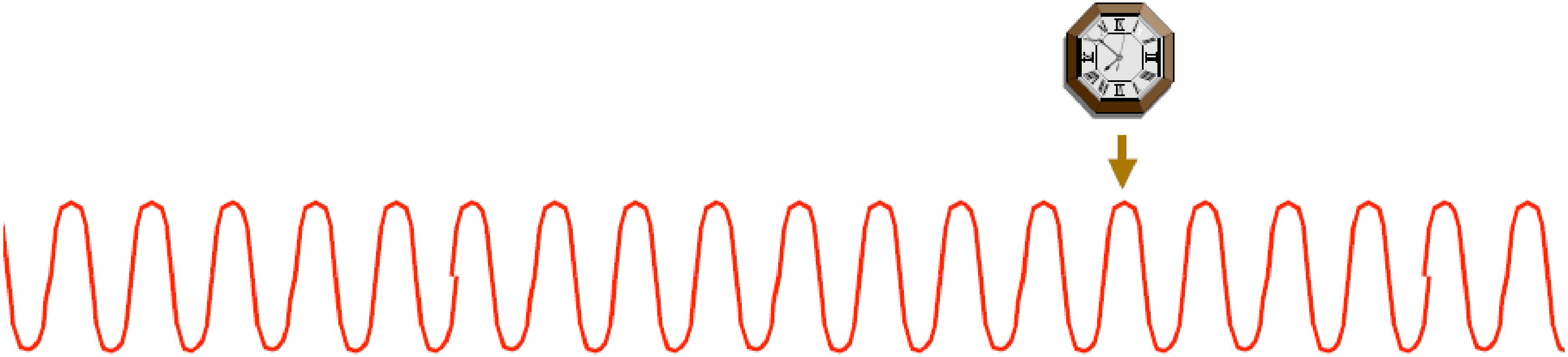
Wavelength

For *periodic* waves, we can identify a *wave length*, λ, by measuring the *distance* between unique points



Period and Frequency

For *periodic* waves, we can identify a *period*, T, by measuring the time taken for a wavelength λ to pass a given point -



The *frequency*, υ, is the inverse of the period i.e.

$$\upsilon = 1/T$$

and is the number of times per second that an oscillation occurs at any fixed point in space

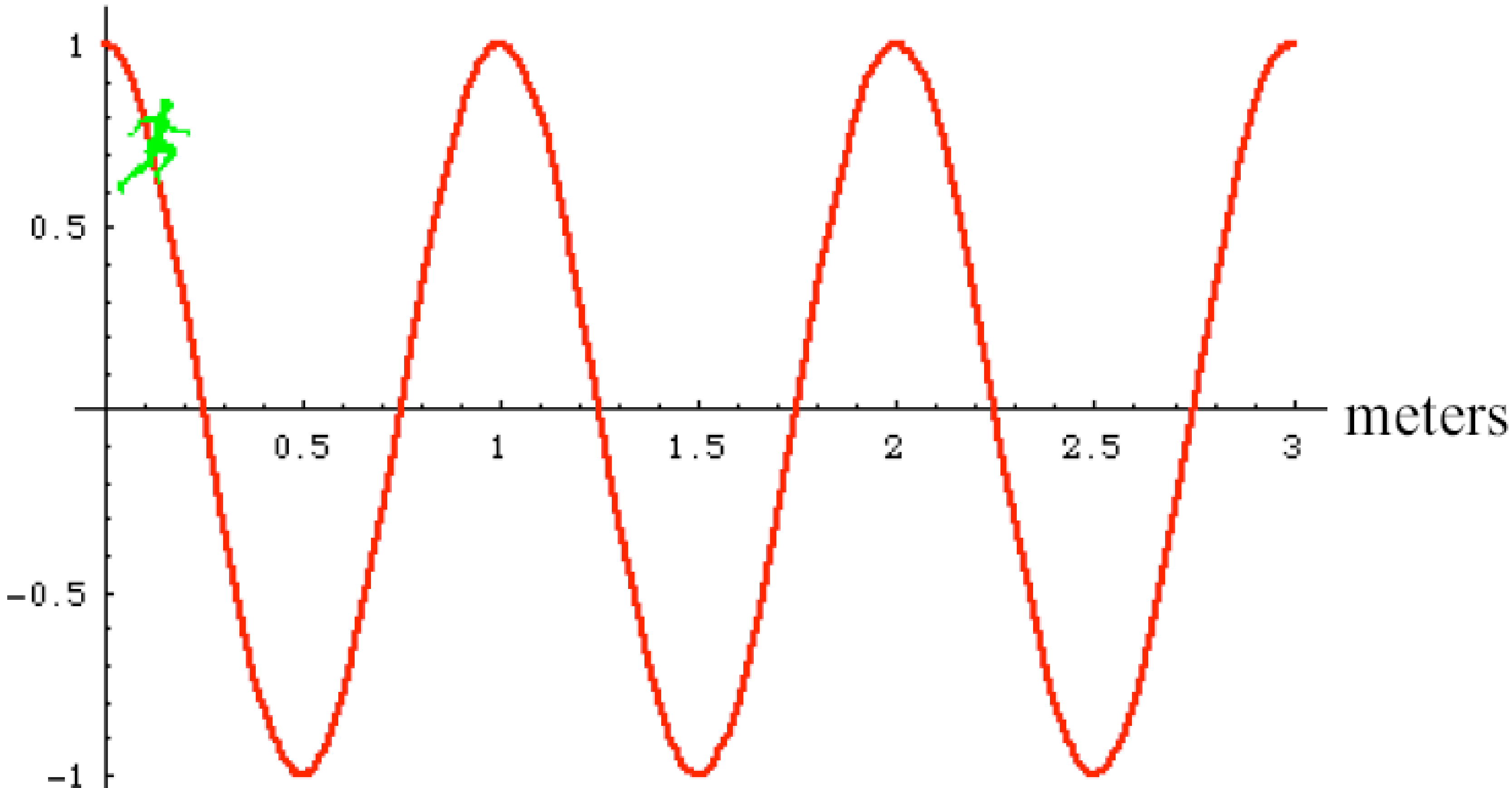
Wavelength of a Wave

What is the wavelength of the red wave?

A) 1m

B) 2m

C) 3m



Scientific notation and metric system

- Powers of 10 give a shorthand notation for very large numbers.
  - $10^3 = 1000$
  - $10^2 = 100$
  - $10^1 = 10$
  - $10^0 = 1$
- Or very small numbers
  - $10^{-1} = 0.1$
  - $10^{-2} = 0.01$
  - $10^{-3} = 0.001$

- Scientists don't use feet or miles to indicate distances
- They use
  - meters (m)
    - 1 meter = 39.4 inches
  - kilometers (km)
    - 1 km = 1000 m = 0.625 mi
  - centimeters (cm)
    - 1 cm = 10^{-2} m = 0.394 inches
  - millimeters (mm)
    - 1 mm = 10^{-3} m
  - nanometers (nm)
    - 1 nm = 10^{-9} m

Clicker question

- The wavelength of green light is around 500 nm. How many wavelengths of green light fit into one cm (0.4 inches, or a fingertip)?
    a) 20 thousand
    b) 50 thousand
    c) Two million
    d) Two billion
    e) 5 billion

Wavelength, Frequency, and Velocity

For *periodic* waves, we can identify a *speed*, v, by

speed = distance/time

speed = Wavelength/Period

speed = Wavelength x frequency

$$v = \upsilon\lambda$$

Wavelength, Frequency, and Velocity

For *periodic* waves, we can identify a *speed*, v, by

Speed = distance/time

Speed = Wavelength/Period

Speed = Wavelength x frequency

$$v = \upsilon\lambda$$

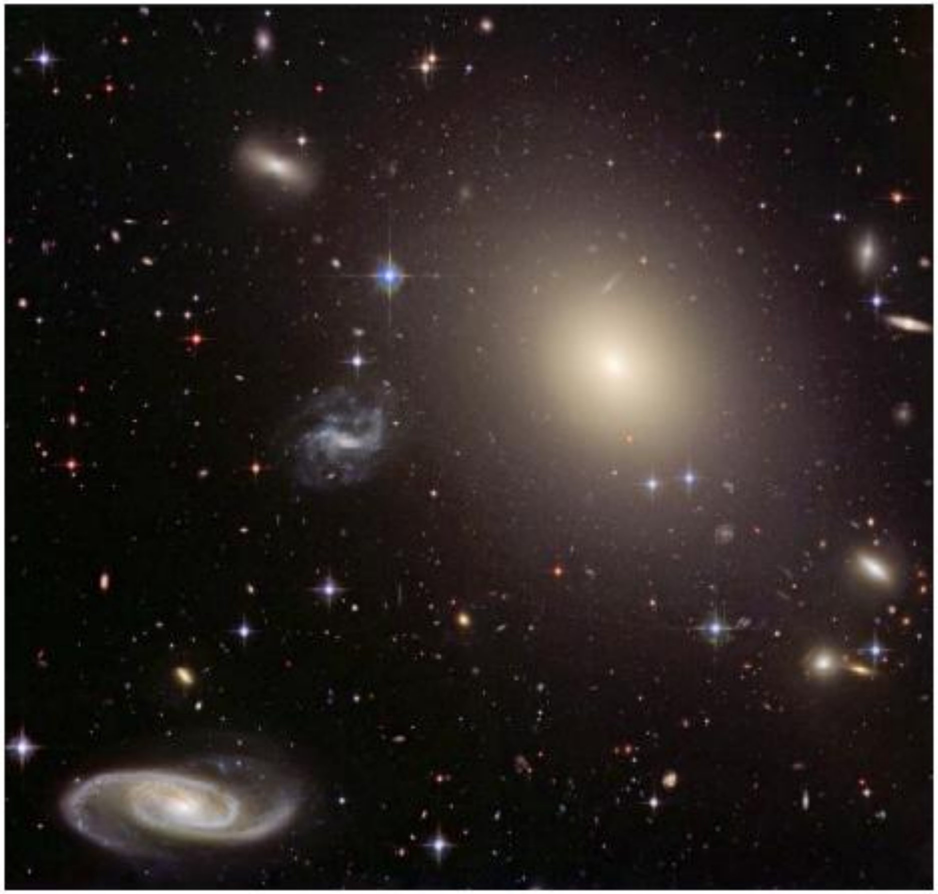
So => $c = \upsilon\lambda$ or $\upsilon = c/\lambda$ or $\lambda = c/\upsilon$

So knowing the **frequency**, we can calculate the **wavelength**

Or knowing the **wavelength**, we can calculate the **frequency**

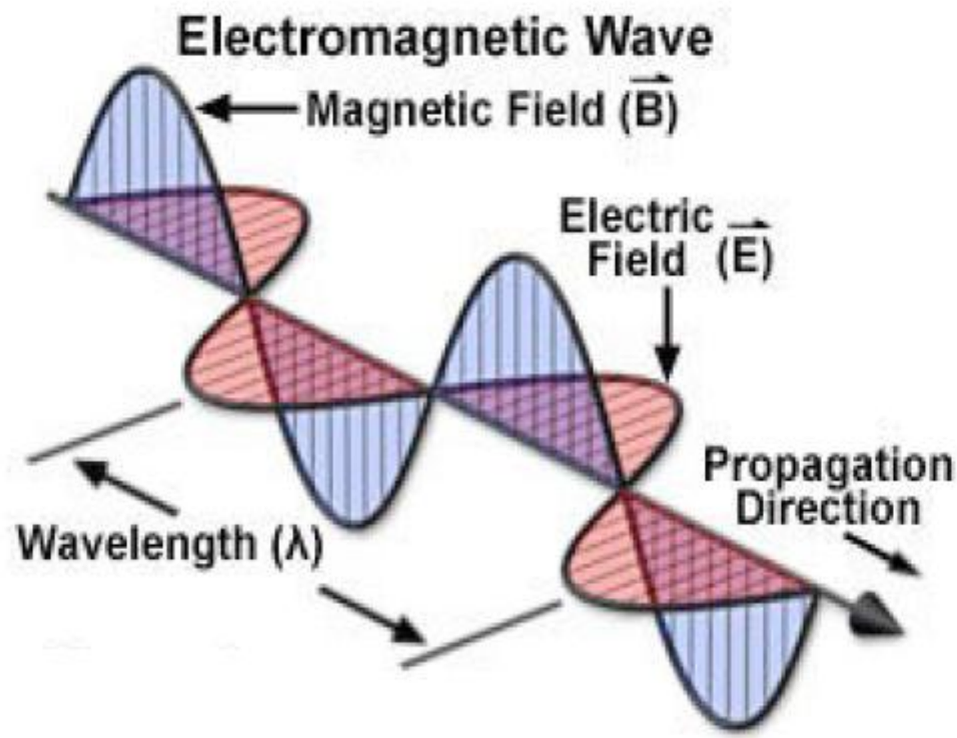
For light waves, the speed in air or vacuum is 3×10^8 meters/sec

Light Waves - part of the EM Spectrum



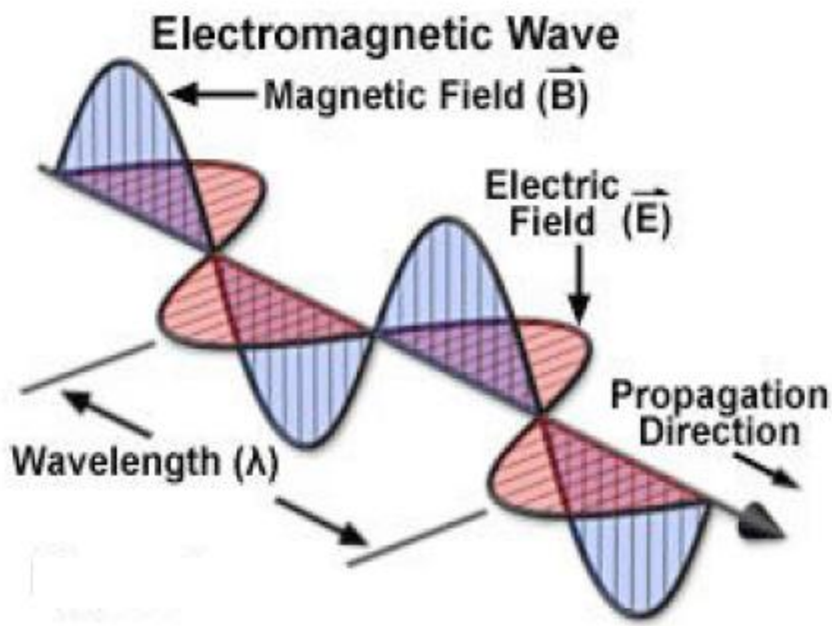
Electromagnetic waves are unlike sound or rope waves because they do not need molecules to travel. This means that electromagnetic waves can travel through air and solid materials - but they can also travel through empty space. This is why astronauts on spacewalks use radios to communicate. Radio waves are a type of electromagnetic wave.

Electromagnetic Waves



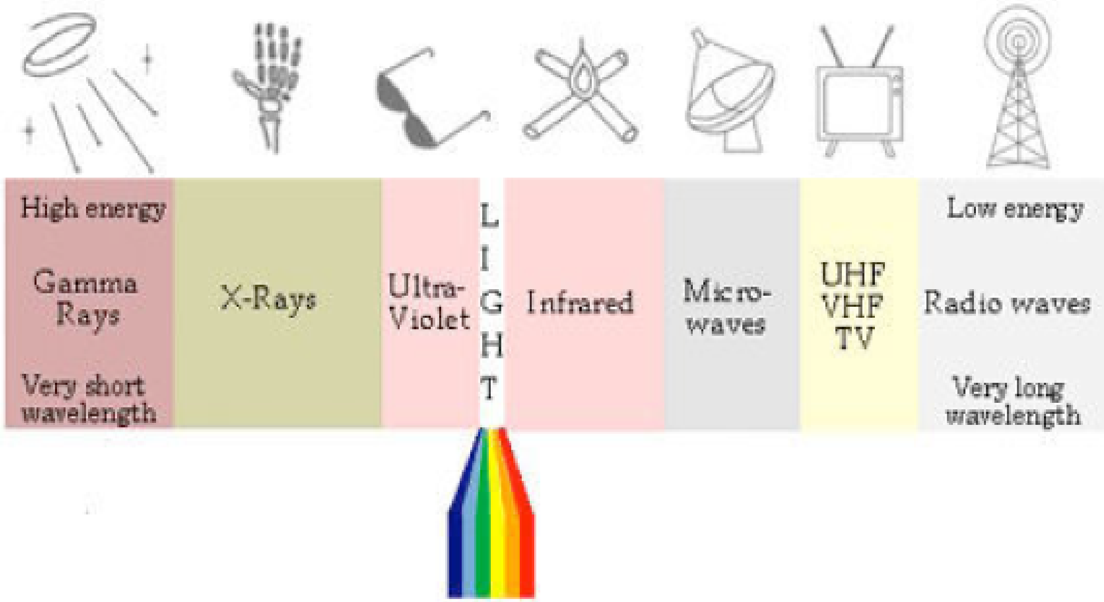
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/electromagnetic/index.html

Electromagnetic Waves



Whether taking the form of a signal transmitted to a radio from the broadcast station, heat radiating from a fireplace, the dentist's X-rays producing images of teeth, or the visible and ultraviolet light emanating from the sun, the various categories of electromagnetic radiation all share identical and fundamental wave-like properties. Every category of electromagnetic radiation, including visible light, oscillates in a periodic fashion with peaks and valleys (or troughs), and displays a characteristic amplitude, wavelength, and frequency that together define the direction, energy, and intensity of the radiation.

http://micro.magnet.fsu.edu/primer/java/electromagnetic/index.html
http://micro.magnet.fsu.edu/primer/java/wavebasics/index.html



Visible light is only a small part of the electromagnetic spectrum.

Most of the electromagnetic spectrum is not accessible to us, unless we're aided by special detectors tuned to the desired energies, much like our eyes are "tuned" to the energy of visible light.

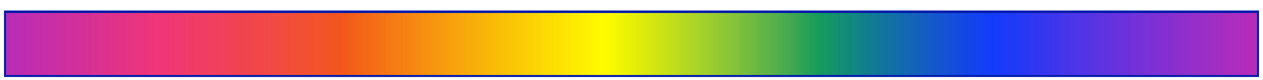
Scientific Notation

milli, written **m**, means 10^{-3}. So 1/1000 of a meter is a millimeter, or 1mm

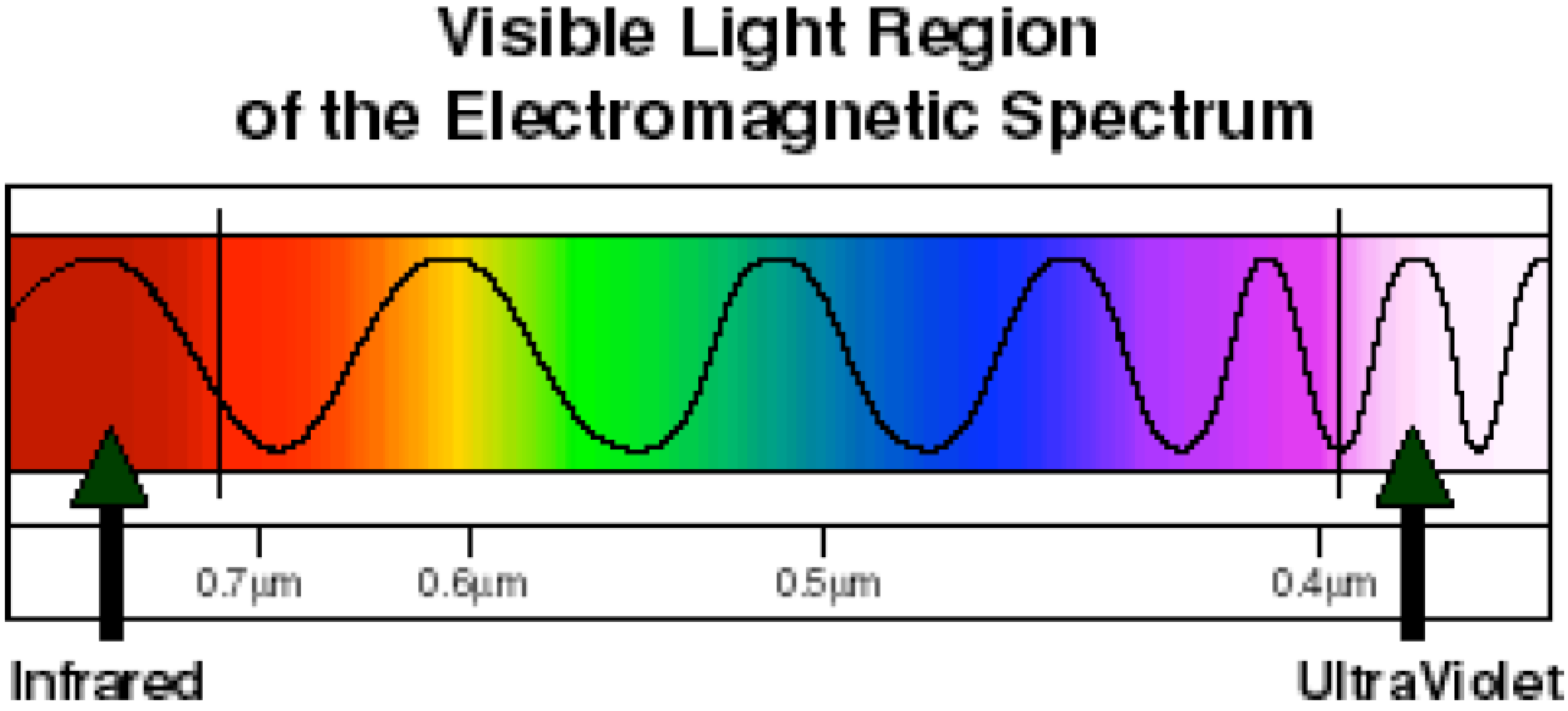
micro, written **μ**, means 10^{-6}. So the wavelength of light is 0.5 micrometers = 0.5μm

mega, written **M**, means 10^{6}. So a 100 MHz FM station is generating waves at 10^{8} Hz

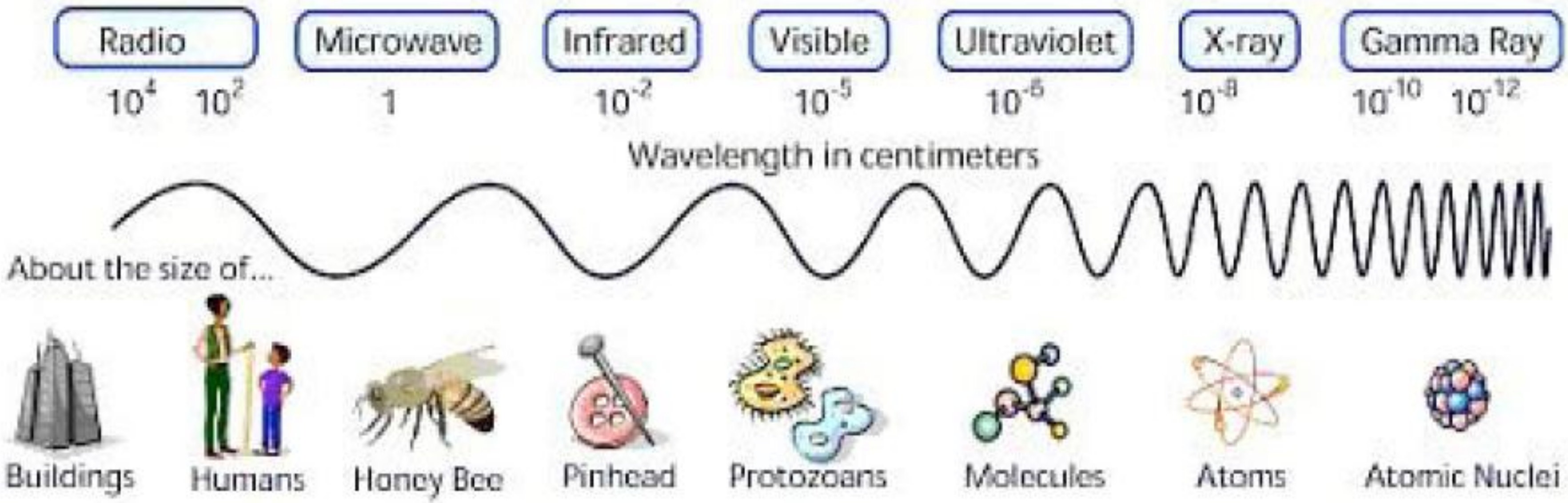
nano, written **n**, means 10^{-9}. So the wavelength of yellow light is 500 nanometers = 500 nm



Waves - the Electromagnetic Spectrum



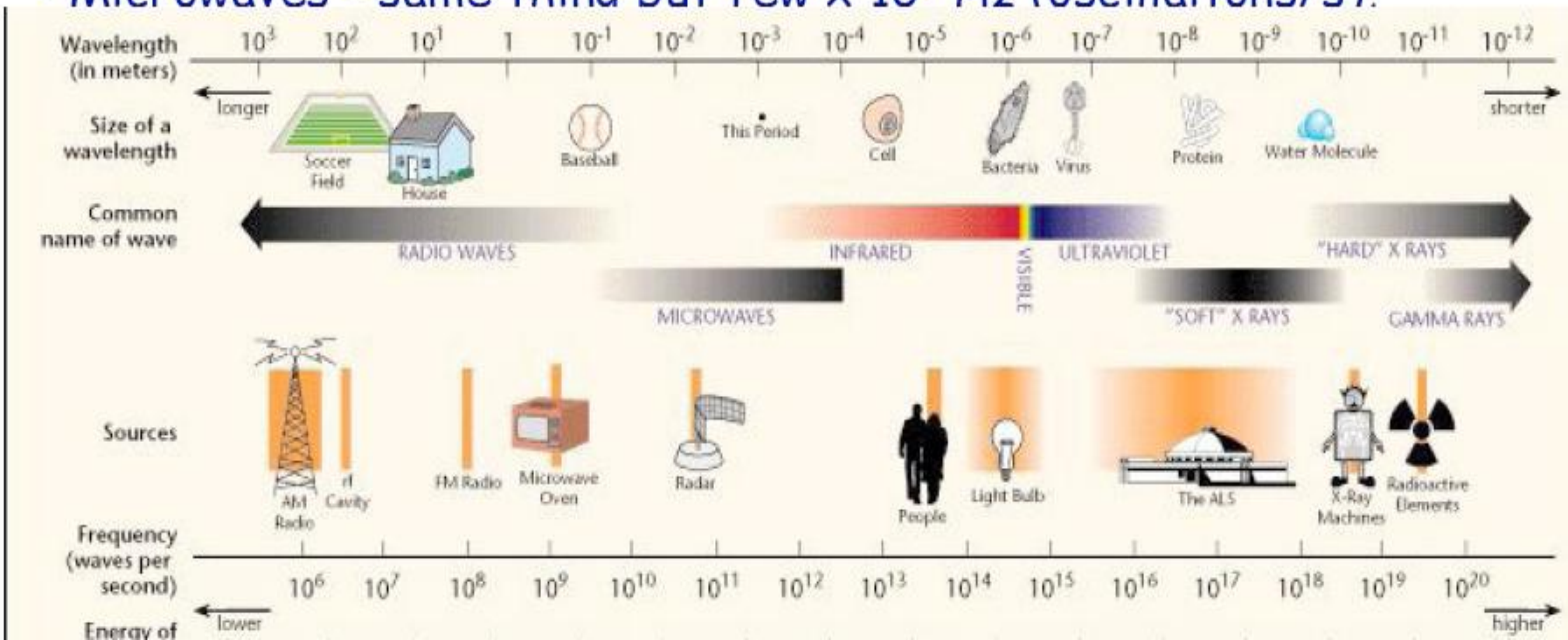
Waves - the Electromagnetic Spectrum



http://imagers.gsfc.nasa.gov/ems/visible.html

Electromagnetic Waves critical to life as we know it!

- Communications – radio, TV, cell phones, portable phones
- Food prep - microwaves
- Vision – visible light
- AM radio 530 to 1600 kHz.
- FM is 88 to 108 MHz.
- TV is 54-206 MHz (each station gets 6 MHz band (Station 1, 54-60 MHz))
- Microwaves - same thing but few x 10^9 Hz (oscillaitons/s).



What we see

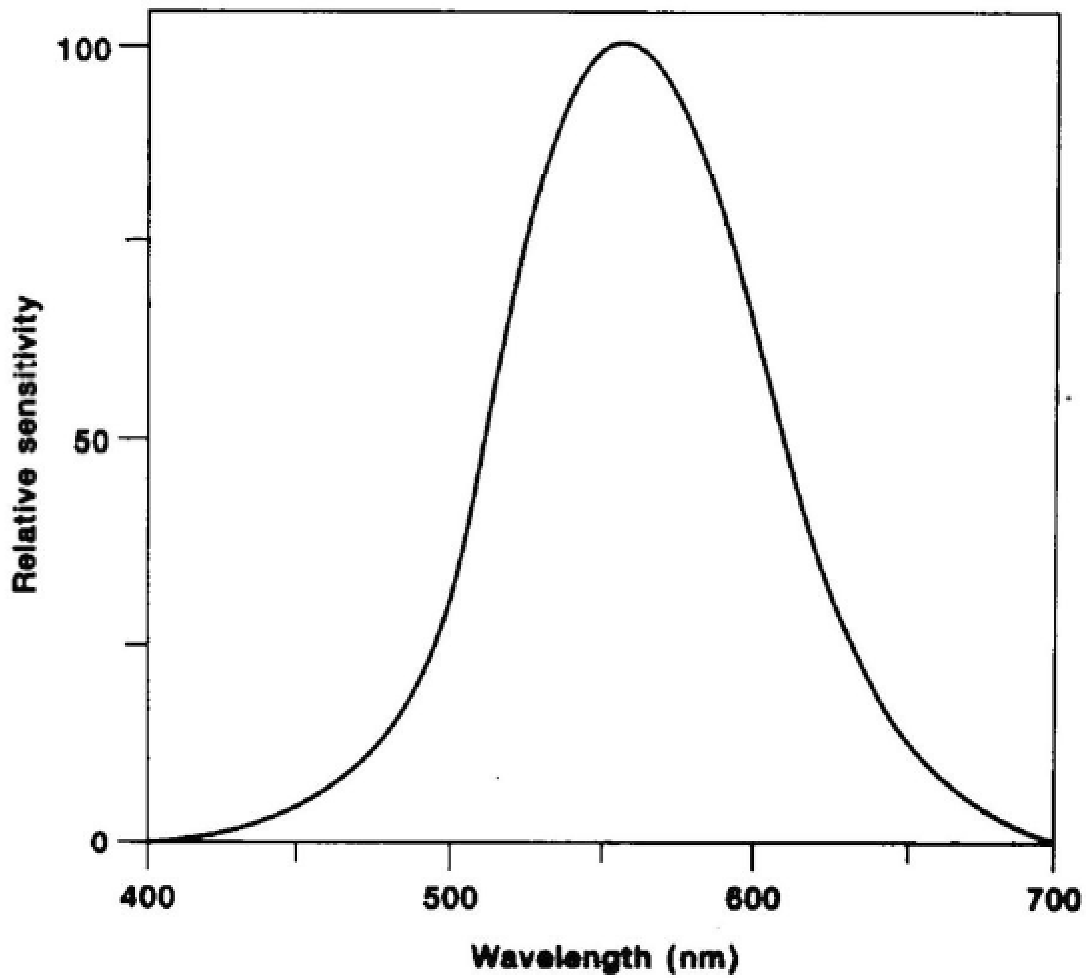
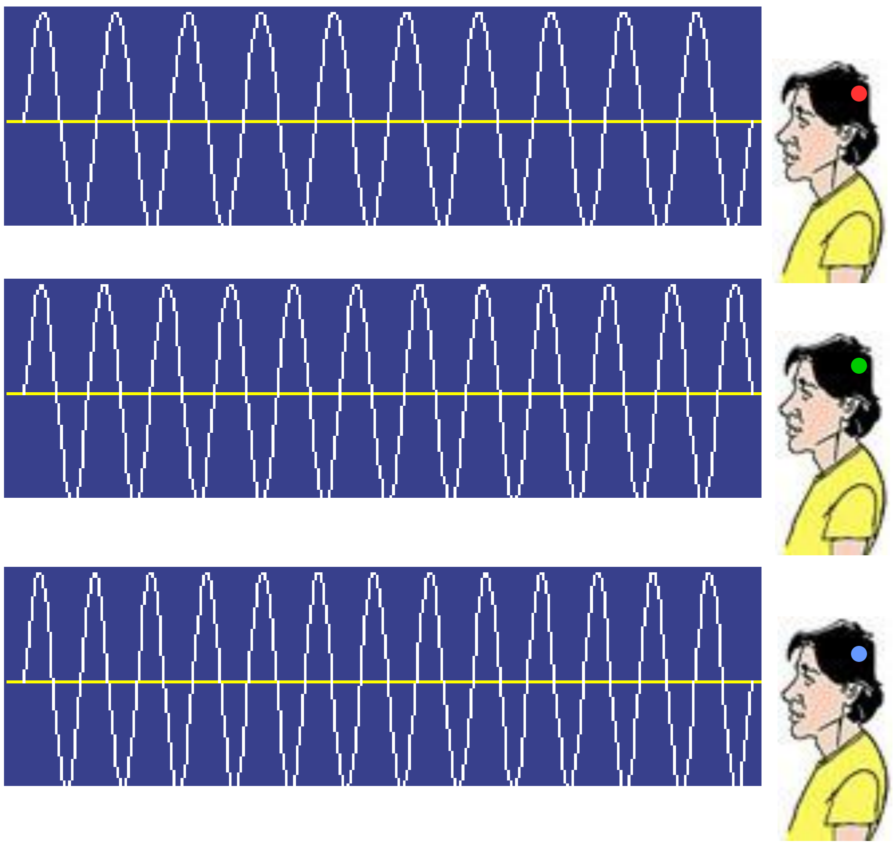


FIGURE 2-3. Sensitivity of the human eye to visible light.

We see color when waves of *different* wavelengths enter enter our eyes!



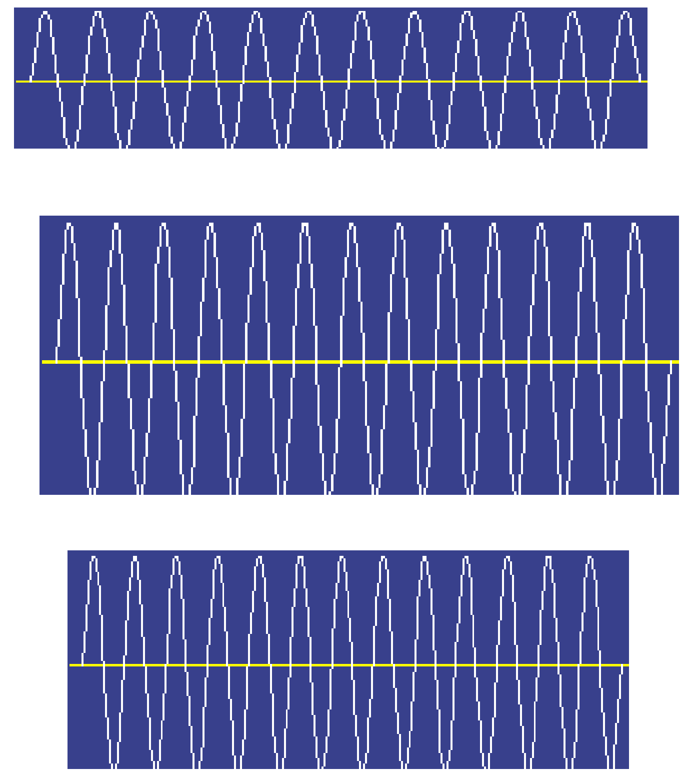
red

green

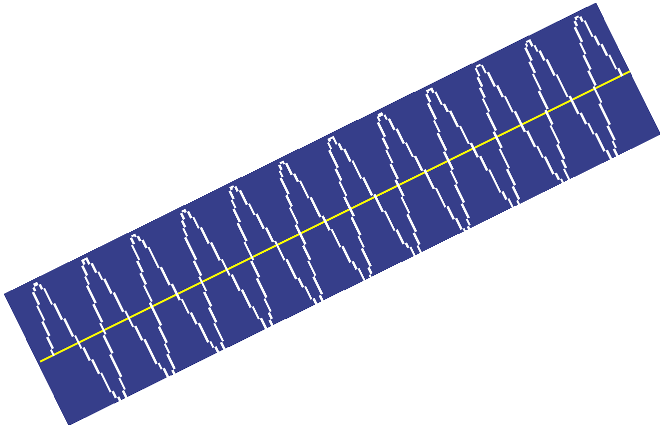
blue

Clicker questions

- Which of the light waves has the longest wavelength?
- Which of the light waves is brightest?
- Which of the light waves has the highest speed in empty space?
  a) b) c)
  d) They all have the same speed

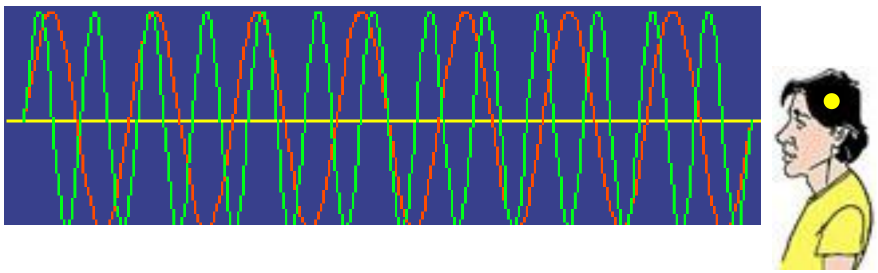


Clicker question

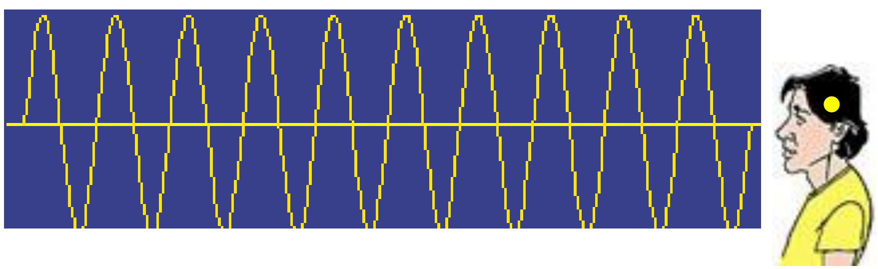


- What does Alex see when the wave at left with wavelength 650 nm goes by him?
  a) Red
  b) Blue
  c) Green
  d) White
  e) Nothing

What happens when two or more waves with different wavelengths reach your eye?

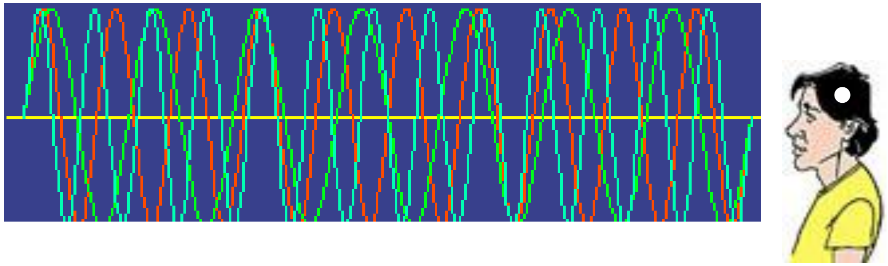


yellow



ALSO **yellow**

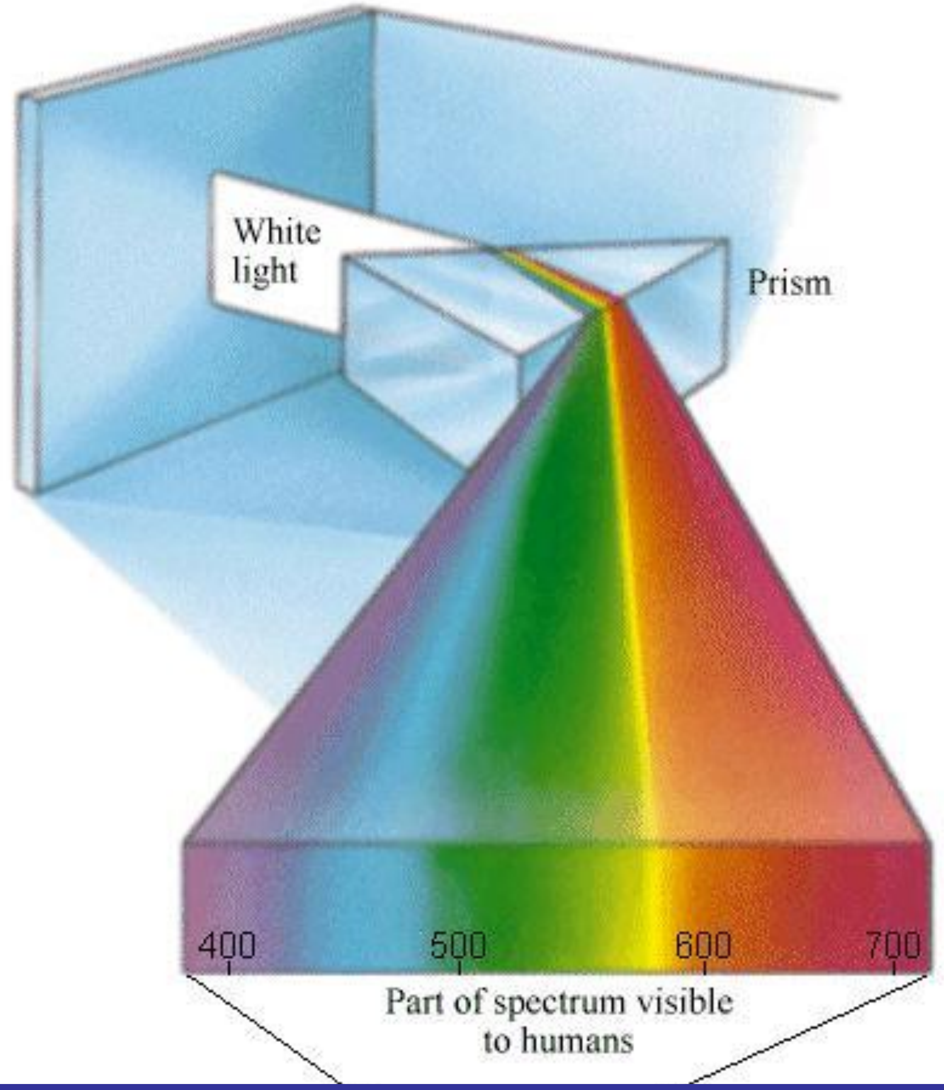
What is white light?



No single wavelength (mono-chromatic) wave appears

when it reaches your eye!

A prism spreads out the over-lapping wavelengths in white light into different spatial locations where they can be seen as colors.



Concept Question

What is the wavelength of the red light?

A) 650 nm

B) 0.650 μm

C) 6.5 m

D) 65 mm

When does an electric field exert a force on a charge?

A. Always
B. Sometimes (changing field)
C. Sometimes (depends on the charge)
D. Sometimes (depends on many things)
E. Something else

Chapter 1 Overview

- Light belongs to a family of waves called electromagnetic (EM) waves *(Physics 2000)*
  - *Other waves: rope waves, water waves, sound waves, etc.*
- Sometimes EM waves are called EM *radiation*
  - Radio waves
  - Radar and similar waves
    - microwaves
    - cell phone waves
  - Infrared or heat waves
  - Ultra-violet (suntan) waves
  - X-rays
  - Gamma rays
- EM waves are created and destroyed by *emission* and *absorption by moving charge*
  - Classical picture *(Phys 2000)*
    - wiggling electrons radiate radio waves or radar waves
    - electrons in an atom are *resonant* with emitted or absorbed light waves or X-rays
  - Quantum picture *(Phys 2000)*
    - change of *state* of electrons in atoms when bundles of wave energy (photons) are emitted or absorbed
- Light sources
  - Incandescent light bulb
  - Neon light
  - Fluorescent light

Waves

- Rope waves
  - Created by oscillation of my hand holding the rope
  - Finite speed of wave, but rope segments do NOT move in direction of wave
  - Rope segments move up and down, not along wave
  - Note the change that occurs when I oscillate my hand faster
- Radio wave transmitter
  - 3 meters wavelength
  - (100 Mhz frequency)
- Google search under keyword "physics"
  - Water waves (circular pattern)
  - Stadium waves

Rays (a single *beam* of light, for example)

- Single light ray
  - Ray from a laser acts like a single light ray
  - Illustrate by laser light through fog
  - Bounce off mirror
  - Bounce off white card
  - Put through water (bending)
- We only see light when a ray enters into our eye
  - Laser light is visible from side because it is *scattered* into our eyes
- Rays from a flashlight
- Rays from a light bulb

- What about light coming from everything in this room? Two kinds of objects:
  - Self luminous objects (lights)
  - Objects which are *not* self-luminous are seen because of light reflected off them
    - Turn out the light and we don't see anything in the room
    - It's all **reflected** light with many rays coming from diffuse surfaces