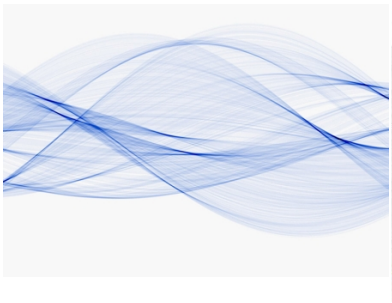
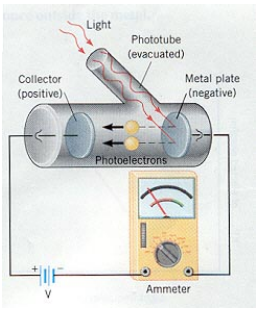
Is light is a wave or a particle? How do we know?





To understand something means to derive it from quantum mechanics,which nobody understands.
-- - unknown origin.

Day 5 Phys 2130:
Questions?
Interference, 2 slit
Starting PhotoElectric

Reminders:
Reading today: Waves .
HW Due last night. How was it?

Goals for waves

Be able to describe and apply conceptual and mathematical representation of waves generally and specifically to E/M waves (and later Quantum)

- Super position
- Interference
- Double slit expt

Introduce Photoelectric Effect

- Describe operation of apparatus
- Make predictions based on models (classical and then QM)

Wave or Particle?

Question arises often throughout course:

- Is something a wave, a particle, or both? How do we know?
- When best to think of as a wave? as a particle?

In classical view of light, EM radiation viewed as a wave (after lots of debate in 1600-1800's).
How decided it is a wave?

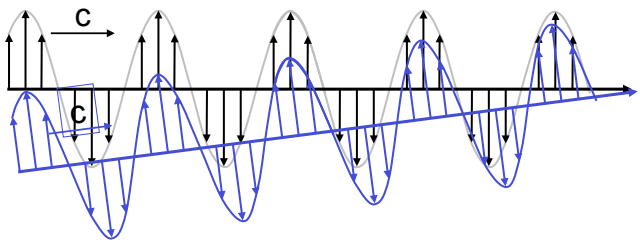
What is most definitive observation we can make that tells us something is a wave?

EM radiation is a wave

What is most definitive observation we can make that tells us something is a wave?

Ans: Observe interference.

Constructive interference:(peaks are lined up and valleys are lined up)

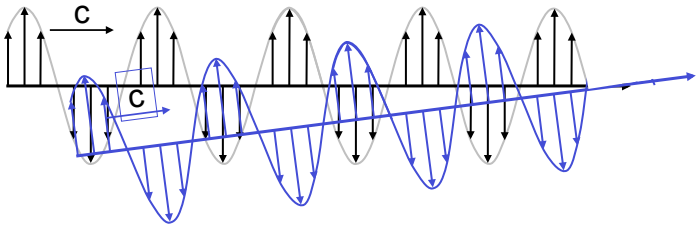


EM radiation is a wave

What is most definitive observation we can make that tells us something is a wave?

Ans: Observe interference.

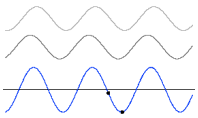
Destructive interference: (peaks align with valleys → *add magnitudes* → *cancel out*)

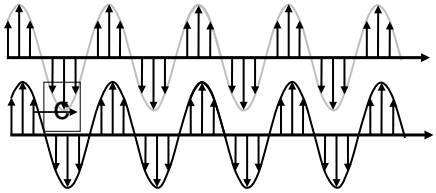


Wave Interference Sim

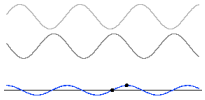
1-D interference

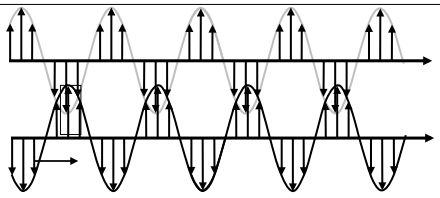
Constructive





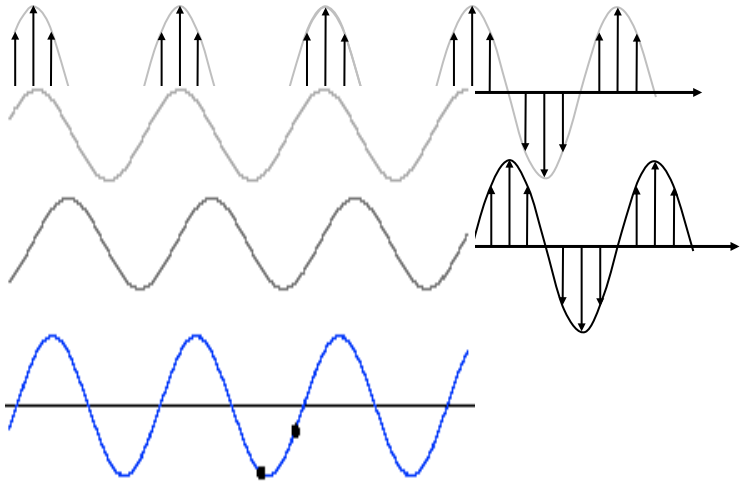
Destructive



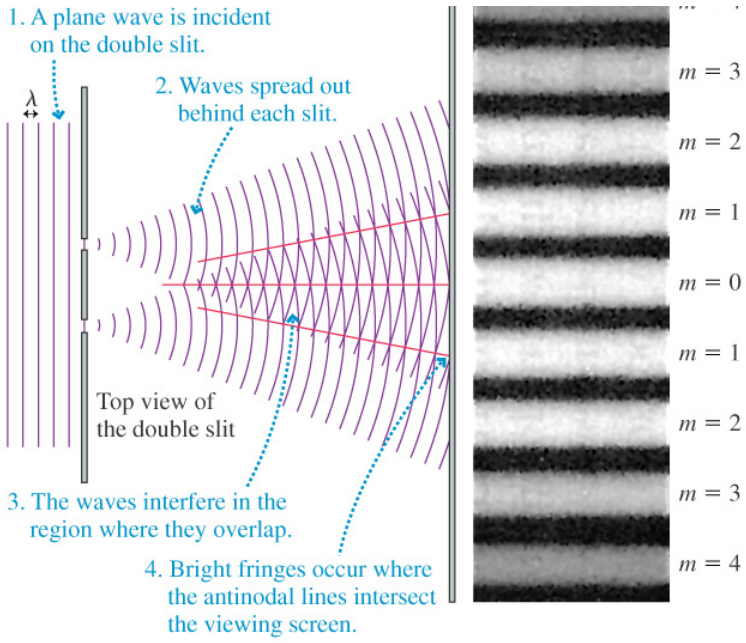


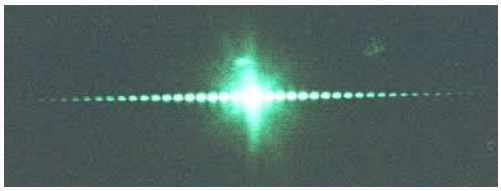
What happens with 1/4 phase interference?

1-D interference

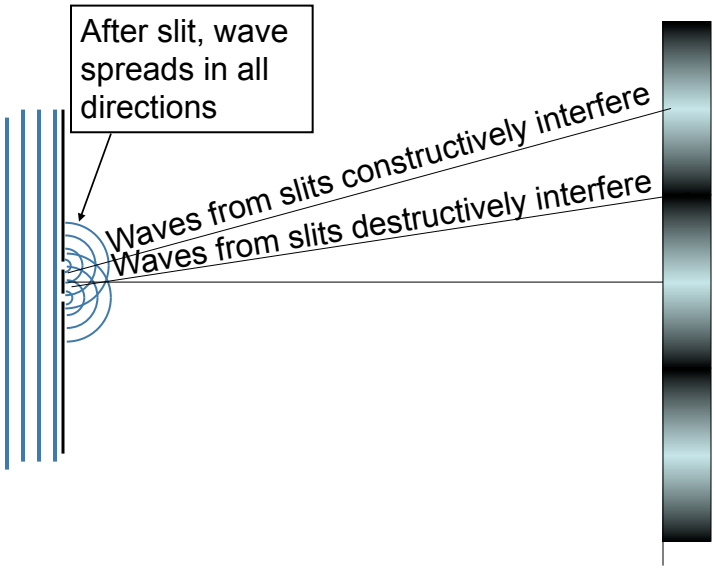


Two slit interference



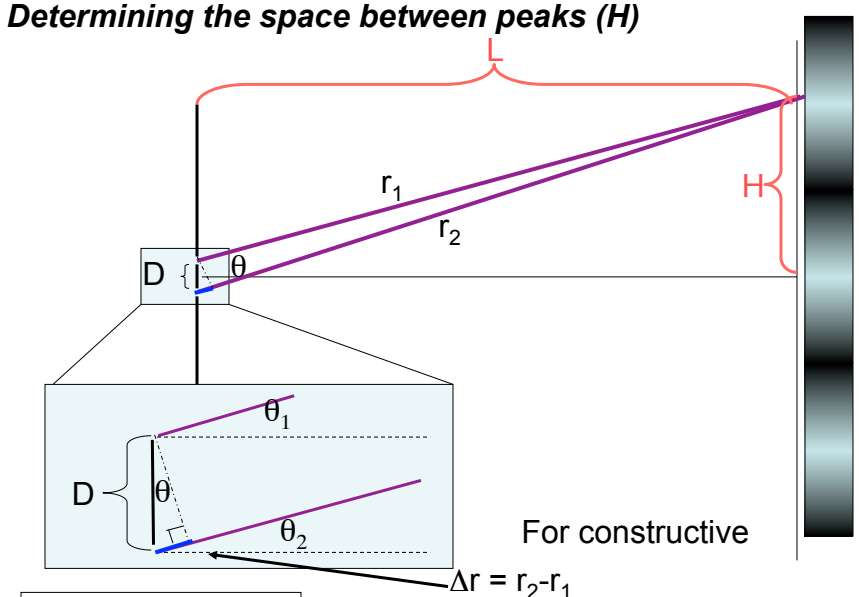


Double-slit experiment with waves



Double-slit experiment

Determining the space between peaks (H)



For constructive

$\Delta r = r_2 - r_1$

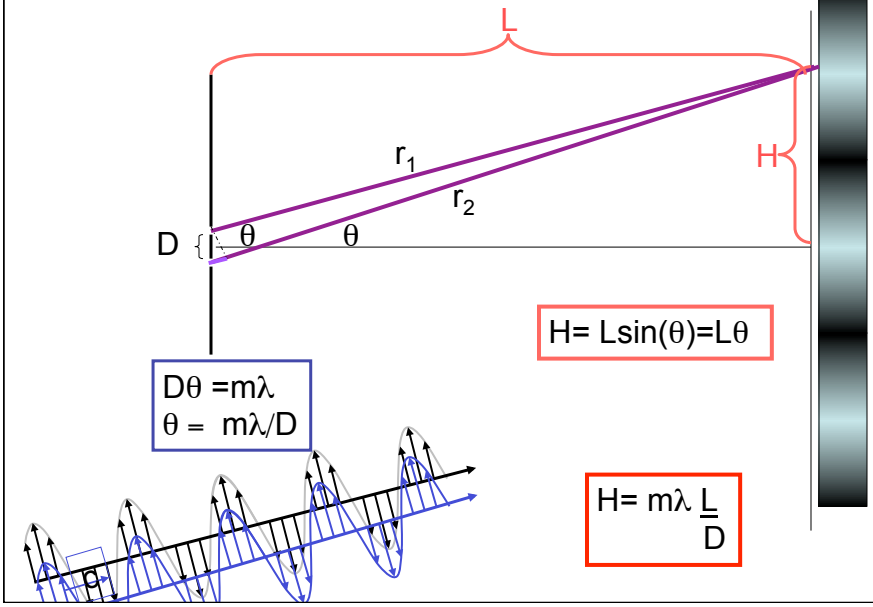
$\Delta r = m\lambda$ (where m=1,2,3…)

$\Delta r = D\sin(\theta) = D\theta = m\lambda$

If screen far away

$\theta_1 \approx \theta_2 \approx \theta$

Are they in phase?
What is difference in path?



$H = L\sin(\theta) = L\theta$

$D\theta = m\lambda$

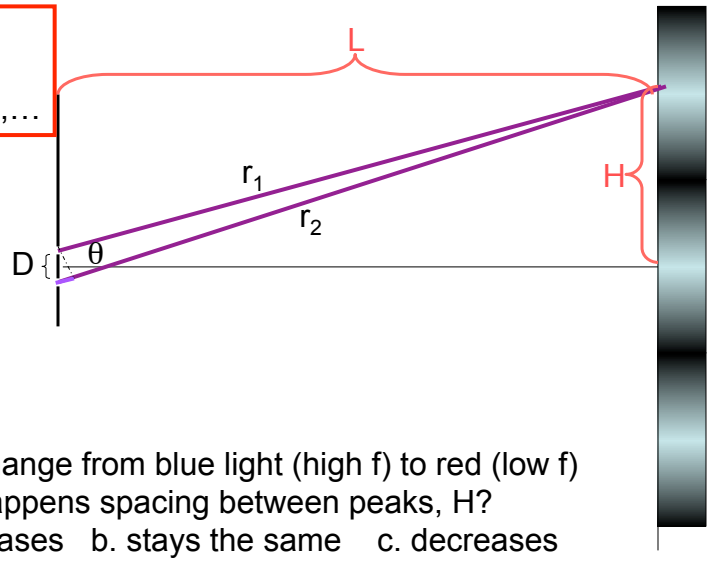
$\theta = m\lambda/D$

$H = m\lambda \frac{L}{D}$

Double-slit experiment:

$H = \frac{m L \lambda}{D}$

$m = 1, 2, 3, \ldots$



If we change from blue light (high f) to red (low f) what happens spacing between peaks, H?

a. increases b. stays the same c. decreases

Double Slit

If we change from blue light (high f) to red (low f) what happens spacing between peaks, H?

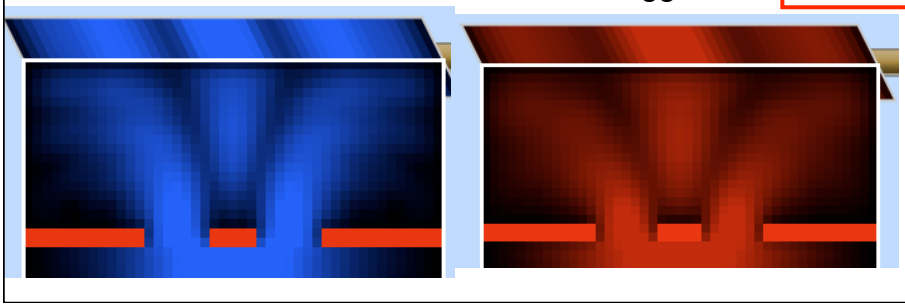
a. increases b. stays the same c. decreases

$H = \frac{m L \lambda}{D}$

$m = 1, 2, 3, \ldots$

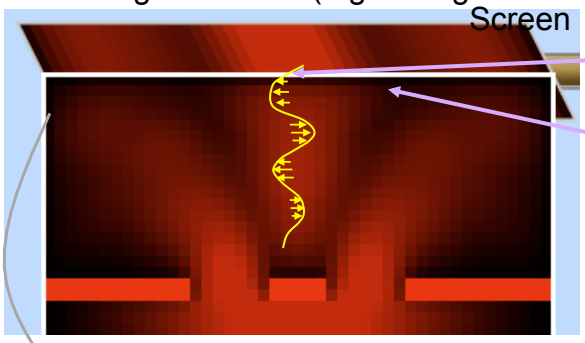
Small λ

Bigger λ



E-field describes probability of finding light there

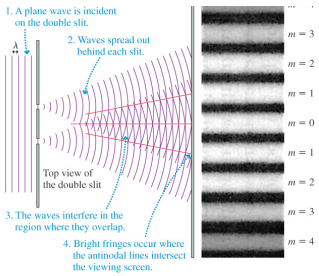
Electromagnetic wave (e.g. hitting screen of double slit)



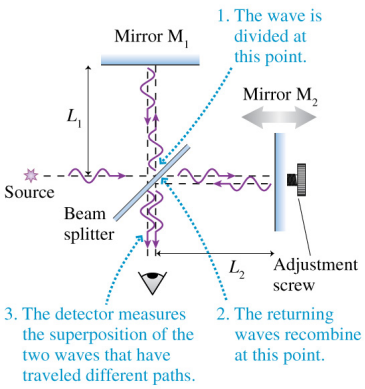
Describe EM wave spread out in space.

Probability of detection (peak / trough)
~ (Amplitude of EM wave)^2

Same idea for interferometer



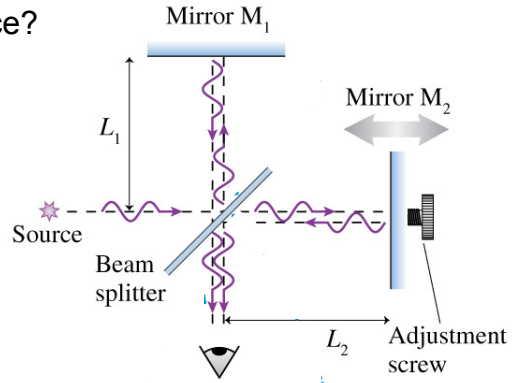
Tool for measuring frequencies, speed, index of refraction…



Michelson interferometer

What's the path difference?

a) L_2-L_1
b) $2L_2$-$2L_1$
c) $2L_2$-L_1
d) 0

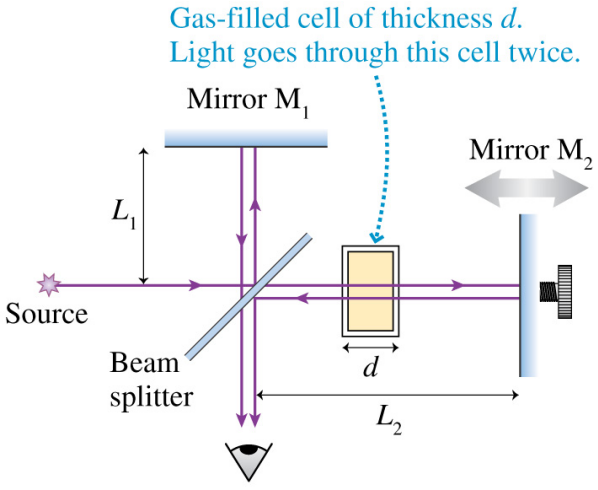


Constructive Interference:

$2L_2 - 2L_1 = m\lambda$

or $L_2-L_1 = m\lambda/2$

One application



What are these waves?

EM Waves (light):

Amplitude E = electric field

E^2 tells you probability of finding light in a spot.

Maxwell's Equations:

$$\frac{\partial^2 E}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 E}{\partial t^2}$$

Solutions are sin/cosine waves:

$$E(x,t) = A\sin(kx - \omega t)$$

$$E(x,t) = A\cos(kx - \omega t)$$

Note:

if $E_1(x,t)$ is a solution

and

$E_2(x,t)$ is a solution

then

$E_1(x,t) + E_2(x,t)$ is a solution

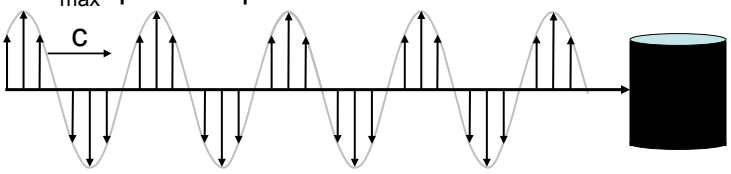
Hence

$E(x,t) = A\sin(kx-\omega t)+B\cos(kx-\omega t)$

Is general solution of E/M

Electromagnetic waves carry energy

E_{max}=peak amplitude



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

Light shines on black tank full of water. How much energy absorbed?

Intensity = $\frac{\text{Power}}{\text{area}} = \frac{\text{energy/time}}{\text{area}} \alpha (E_{avg})^2$

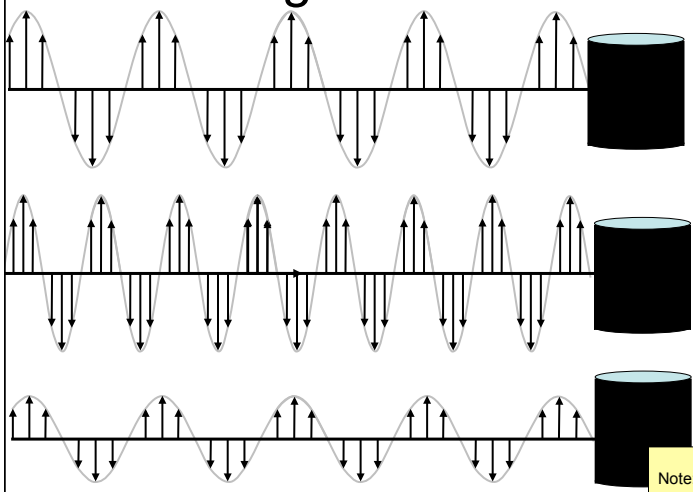
$I = \varepsilon_o c E^2$

α (amplitude of wave)^2 α E_{max}^2

Note: you showed on HW that E = cos(kx + ωt)

Does time averaged E_{max}^2 (ω,x,t)?

Electromagnetic waves carry energy



Note: $E_{1max}=E_{2max}>E_{3max}$ and $f_1 = f_3 < f_2$

Which barrel will heat up the fastest?

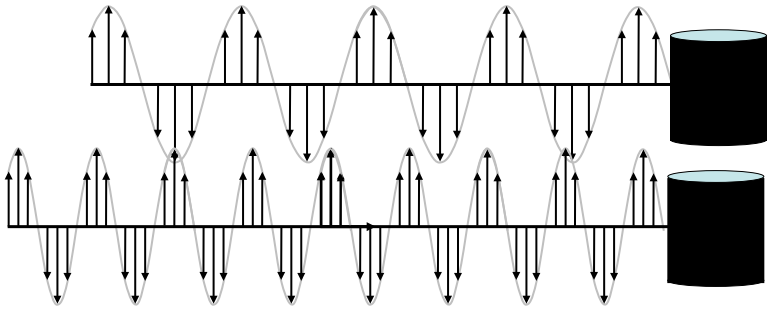
a. 2>1>3 b. 1>2>3 c. 1=2>3

d. 1=3>2 e. 2>1=3

Answer is c.

Intensity = power/area α E_{max}^2

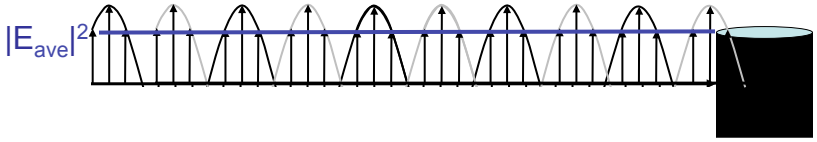
Recap: Intensity $\propto E_{max}^2$ … what about frequency?



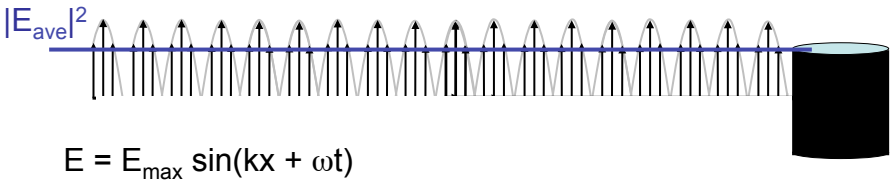
vs.

Distinguish between energy carried by a beam of light (classical) vs. energy in a single quantum of light

Classical waves: Intensity ~ E_{max}^2



vs.



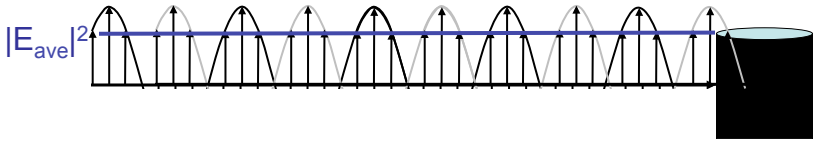
$E = E_{max} \sin(kx + \omega t)$

$|E_{ave}|^2 \sim E_m^2$ AVE $[\sin^2 (kx + \omega t)]$

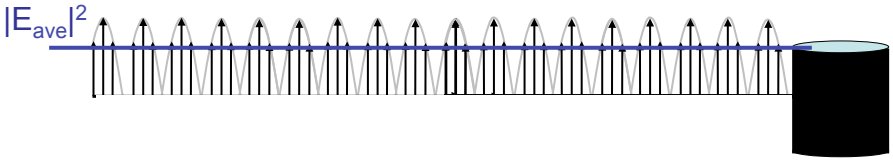
$\sin^2 (kx + \omega t) + \cos^2 (kx + \omega t) = ??$
$= 1$

So if we average over time, E is independent of ω or f

Classical waves: Intensity ~ E_{max}^2



vs.



"Why do higher frequency gamma rays … carry more energy that lower frequency radio waves, but frequency has nothing to do with intensity?"

Energy carried by a beam of light
vs. Energy in a single quantum of light

The Photoelectric Effect

Photoelectric effect: experiment showing light is <u>also</u> a particle. Energy comes in particle-like chunks- basics of quantum physics. (energy of one chunk depends on frequency, wave-like beam of light has **<u>MANY</u>** chunks, energy of beam is sum)

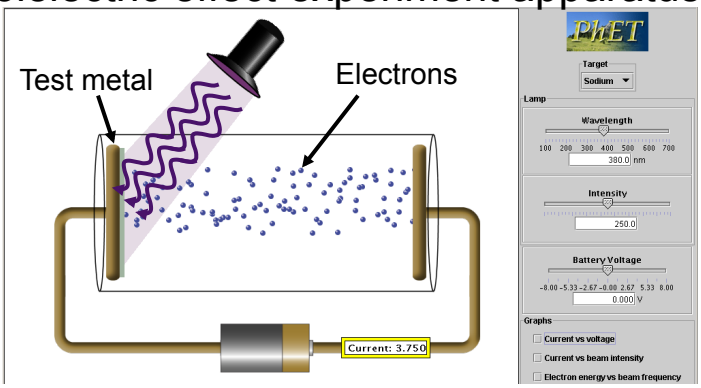
<u>Next 2 classes:</u>

I. Understand the P.E. experiment and what results you would expect if light were a classical wave (like physicists at the time expected the experiment should give).
II. What experimental results it actually did give.
III. The implications/interpretation of the results.

<u>Important to take notes</u>

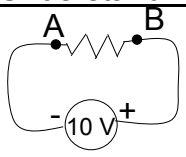
a) record predictions to compare with experiment.
b) record results of experiments.

Photolelectric effect experiment apparatus.



Two metal plates in vacuum, adjustable voltage between them, shine light on one plate. Measure current between plates.

<u>I. Understanding the apparatus and experiment.</u>



Potential difference between A and B = +10 V
Measure of energy an electron gains going from A to B.