Welcome back to PHY 3305

Today's Lecture:

Double Slit Experiment

Matter Waves

Louis-Victor-Pierre-Raymond,
7th duc de Broglie
1892-1987

ANNOUNCEMENTS

- Reading Assignment for Thursday, Sept 28th: Chapter 4.3.
- Problem set 6 is due Tuesday, October 3rd at 12:30 pm.
- Regrade for problem set 5 is due Tuesday, October 3rd at 12:30 pm.
- Deadline for registering for the Texas Section APS meeting is fast approaching! It is tomorrow — Wednesday, Sept 27th!
- Dr. Cooley will be out of town Thursday, October 5th. Mr. Thomas will be in class to lead the lecture discussion in her place.

DOUBLE SLIT EXPERIMENT

http://phet.colorado.edu/en/simulation/quantum-wave-interference

Experiment 1:

High intensity beam.
What behavior do we expect?

Experiment 2:

Single photons.
What behavior do we expect?

*note to self: leave single photon experiment running.

Modern Physics Presentations

The presentation component of the course is designed to accomplish three goals:

1. Acquire a working familiarity with an aspect of Modern Physics not covered directly in lecture.
2. Organize technical material into a coherent document describing your chosen topic.
3. Deliver the material to a group in a logical and ordered way such that the concepts are adequately understood.

MODERN PHYSICS PRESENTATIONS

You will be expected to do the following:

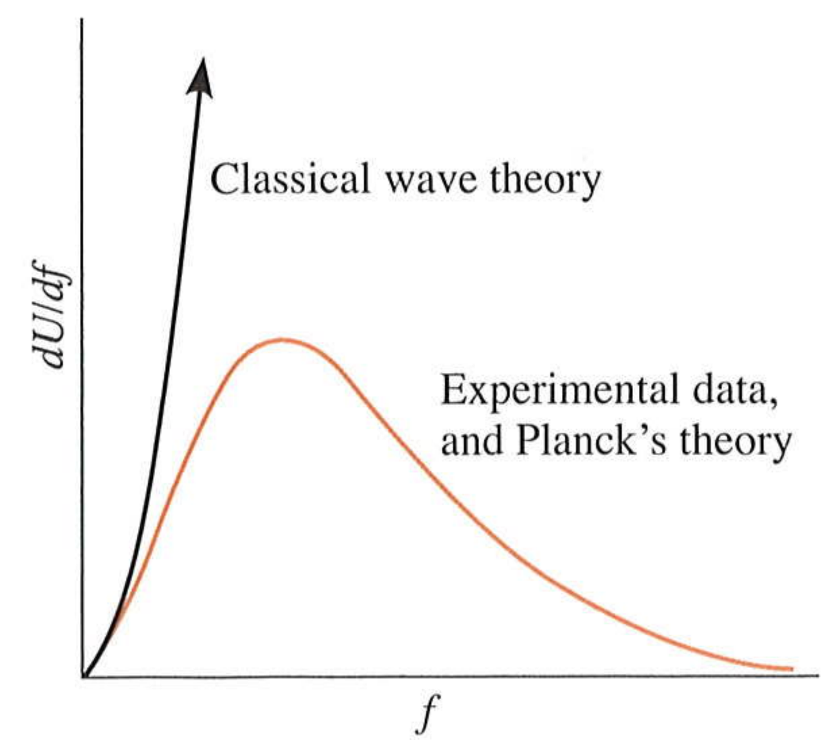
1. Deliver a 15 minute presentation on the topic.
2. Adhere to the basic principles of good presentation design.
3. Answer questions from the audience on the subject.
4. Ask questions of your classmates on their subjects.

This week you will be asked to propose three topics for your presentation. This will be part of your homework assignment. Ideas can be found on the course website:

http://www.physics.smu.edu/cooley/phy3305/presentations.html

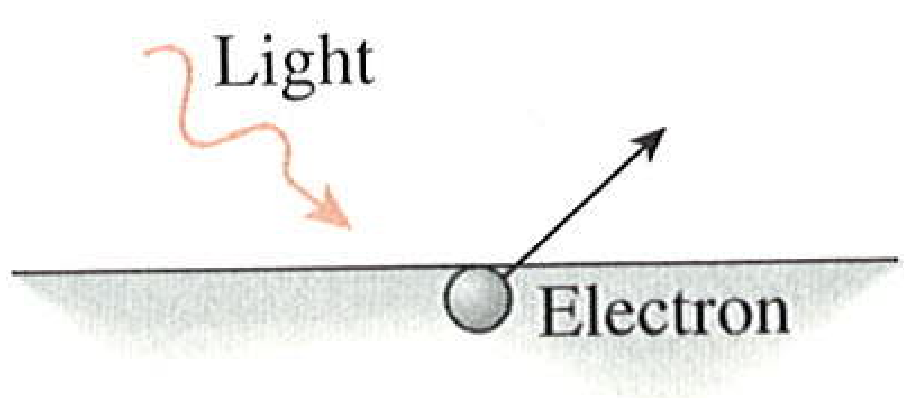
Review: Light as Particles

- Blackbody Radiation
  - Incoming radiation is completely absorbed by a blackbody. Outgoing radiation is due entirely to the thermal motion of charges in the wall of the cavity.
  - If light were a wave, we would expect the spectral density to continuously increase as a function of frequency.
  - Observed a turnover in the spectral density as frequency increased.
  - Plank proposes that the average energy of a given wave is discrete
    - not continuous as in classical theory.



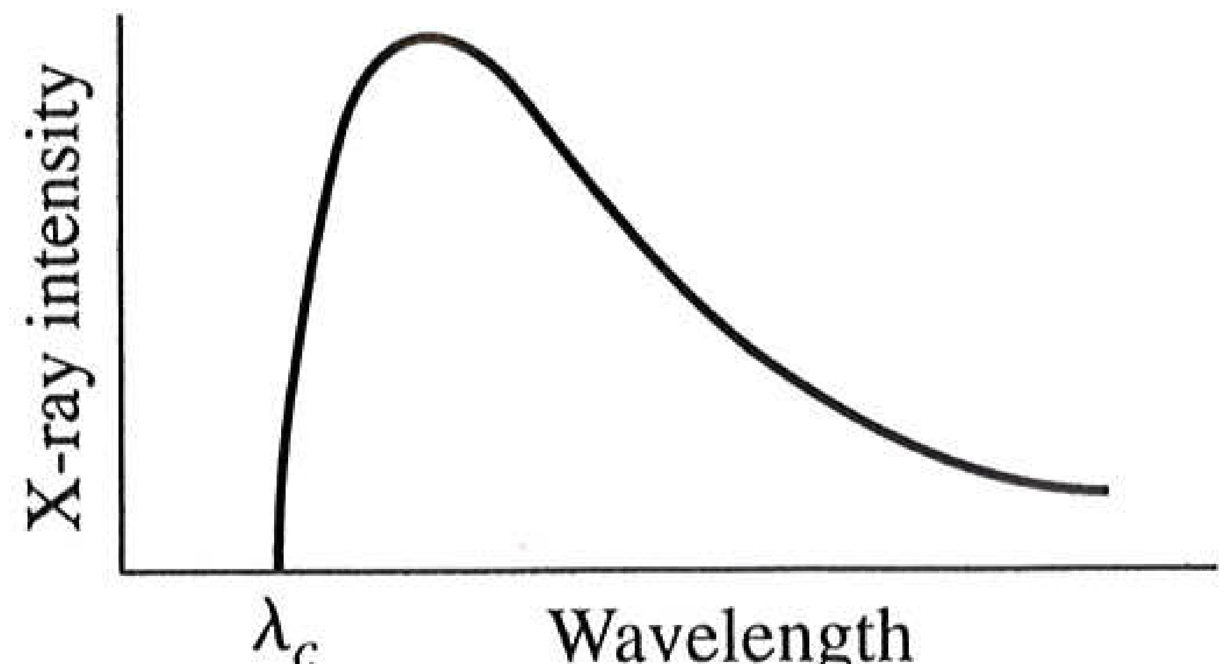
Review: Light as Particles

- Photoelectric Effect
  - Light is absorbed into a metal and electrons ("photoelectrons") are ejected as a consequence of this absorption.
  - If light were a wave, it should be able to eject electrons at any wavelength.
  - Increasing the intensity at any frequency should make the electrons more energetic.
  - Einstein proposes that light behaves as a collection of particles called photons.



REVIEW: LIGHT AS PARTICLES

- Bremstrahlung radiation produced by striking x-rays against a metal target has a cut-off frequency.
- If the electromagnetic radiation produced this way were thought of as waves, their frequency should cover the entire spectrum.
- If radiation is quantized, the minimum energy at a given frequency is that of a single photon.
- The cut-off frequency is given by the KE of a single photon.



0.050nm

error in textbook

Review: Light as Particles

- Compton Effect
  - Xrays incident on a material are scattered off electrons in the material
  - Classical physics predicts that EM waves incident on a material will emit EM waves in all directions with the same frequency as the incoming EM wave.
  - Observed emitted waves at frequencies lower than that of the incoming wave.
  - Light, a particle and not a wave, collides with an electron and in ejecting the electron scatters backward with less energy.

DOUBLE SLIT EXPERIMENT

http://phet.colorado.edu/en/simulation/quantum-wave-interference

Wave nature is apparent even when detecting only one particle at a time.

Question: Which slit did the 17th photon pass through?

Detecting photons enroute to the slits or screen interferes with the wave/particle nature. In our case the single photons have to be thought of as passing the slits at the same time - wavelike behavior. Changing the experiment forces the photon to interact with something, exposing its particle nature and changing the outcome of the experiment.

Phet Demonstration illustrates this!

RECAP

- The double-slit experiments revealed the nature of light to behave as waves and particles.
- The dual nature is not particle vs. wave, but rather complimentary between the two.
- When a phenomenon is detected as particles, we can not say for certain where it will be detected. We can only determine the probability of finding it in a certain location.
- Probability of finding a particle in a given location is proportional to the square of the amplitude of the associated wave.

$$P \propto A^2$$

DOUBLE SLIT EXPERIMENT

http://phet.colorado.edu/en/simulation/quantum-wave-interference

Now lets do the same simulation, this time using electrons.

Video Lecture

de Broglie's Hypothesis:

- The relationships

  $f = E/h \quad \& \quad \lambda = h/p$

  apply to ALL particles, i.e. even those with mass

Calculating deB Wavelengths

- What is the de Broglie wavelength of
  a) A 1 eV photon
  b) A 1 eV electron (electron w/ $E_{kE} = 1$ eV)
  c) A 1 eV proton ($E_{kE} = 1$ eV)
  d) A 1 eV football ($E_{kE} = 1$ eV)

Hints:
$m_e c^2 = 511$ keV
$m_p c^2 = 940$ MeV
1 kg football $= 5 \times 10^{35}$ eV/c^2

Calculating deB Wavelengths

$$\lambda = \frac{h}{p} = \frac{hc}{pc} = \frac{hc}{\sqrt{E_{KE}^2 + 2E_{KE}mc^2}}$$

hc = 1240 eV·nm

Particle	E_k	m_0	$(2E_k m_o c^2 + E^2_k)^{-1/2}$	
γ	1 eV	0 eV/c^2	$\cancel{0}$ + 1^2	
e	1 eV	511×10^3 eV/c^2	$2 * 511 \times 10^3 * 1$ + $\cancel{1^2}$	
p	1 eV	940×10^6 eV/c^2	$2 * 940 \times 10^6 * 1$ + $\cancel{1^2}$	
football	1 eV	1 kg = 5×10^{35} eV/c^2	$2 * 5 \times 10^{35} * 1$ + $\cancel{1^2}$	

Calculating deB Wavelengths

- What is the de Broglie wavelength of

Hints:
$m_e c^2 = 511$ keV
$m_p c^2 = 940$ MeV
1 kg football = 5×10^{35} eV/c^2

e) A 10^{12} eV photon

f) A 10^{12} eV electron (electron w/ $E_{kE} = 10^{12}$ eV)

g) A 10^{12} eV proton ($E_{kE} = 10^{12}$ eV)

h) A 10^{12} eV football ($E_{kE} = 10^{12}$ eV)

Calculating deB Wavelengths

$$\lambda = \frac{h}{p} = \frac{hc}{pc} = \frac{hc}{\sqrt{E_{KE}^2 + 2E_{KE}mc^2}}$$

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Particle	E_k	m_0	$(2E_k m_o c2 + E^2{}_k)^{-1/2}$
γ	10^{12} eV	0 eV/c^2	$\cancel{0}$ + $(10^{12})^2$
e	10^{12} eV	511×10^3 eV/c^2	$\cancel{2*511\times10^3*10^{12}}$ + $(10^{12})^2$
p	10^{12} eV	940×10^6eV/c^2	$\cancel{2*940\times10^6*10^{12}}$ + $(10^{12})^2$
football	10^{12} eV	1 kg = 5×10^{35} eV/c^2	$2*5\times10^{35}*10^{12}$ + $\cancel{(10^{12})^2}$

A free electron and a free proton have the same speed (assume $v \ll c$). This means that compared to the de Broglie wave associated with the proton, the de Broglie wave associated with the electron has:

$\lambda = h/p$

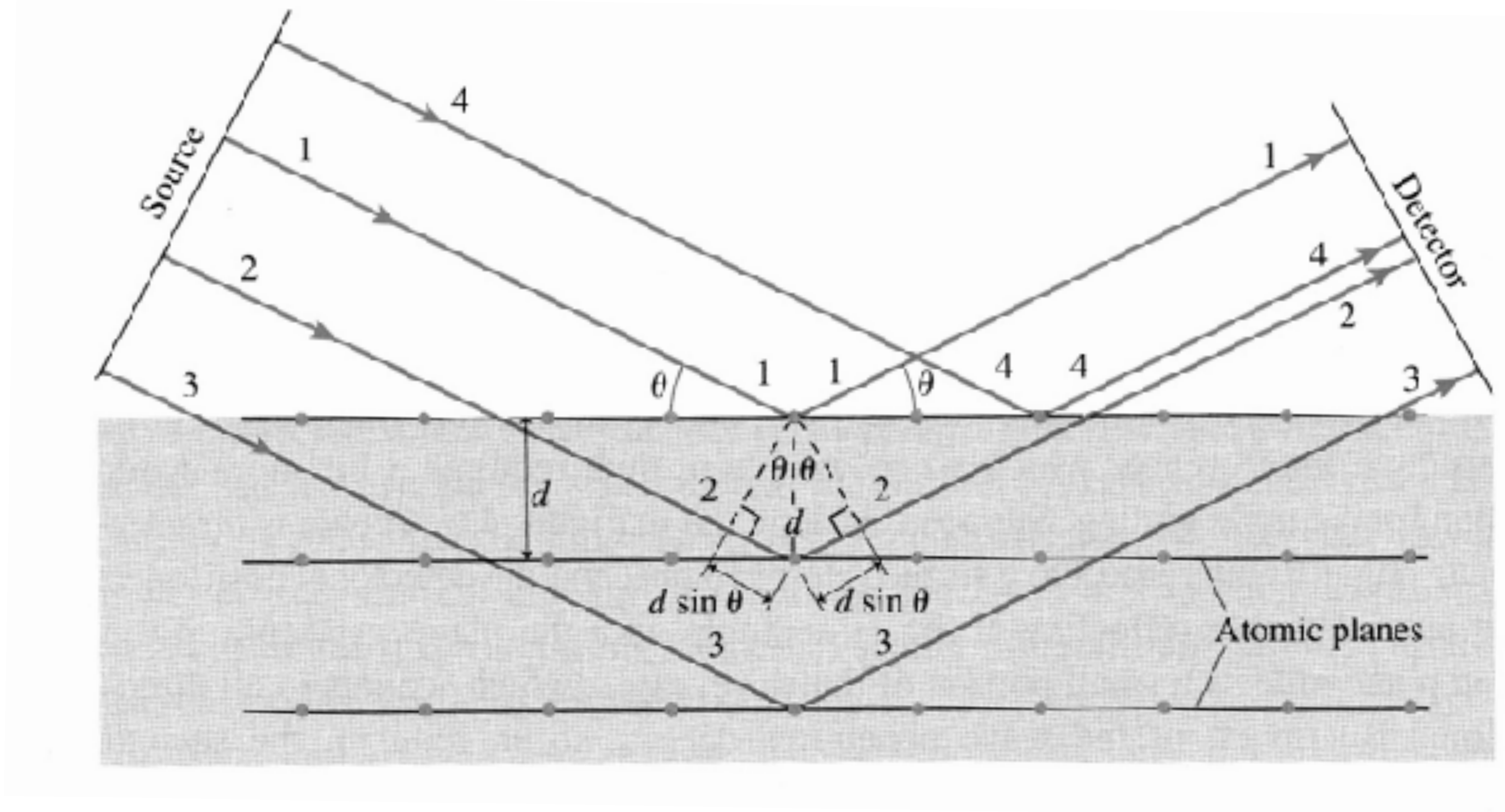
A) a shorter wavelength and a greater frequency

B) a longer wavelength and a greater frequency

C) same wavelength and same frequency

D) same wavelength and a greater frequency

E) a longer wavelength and a smaller frequency

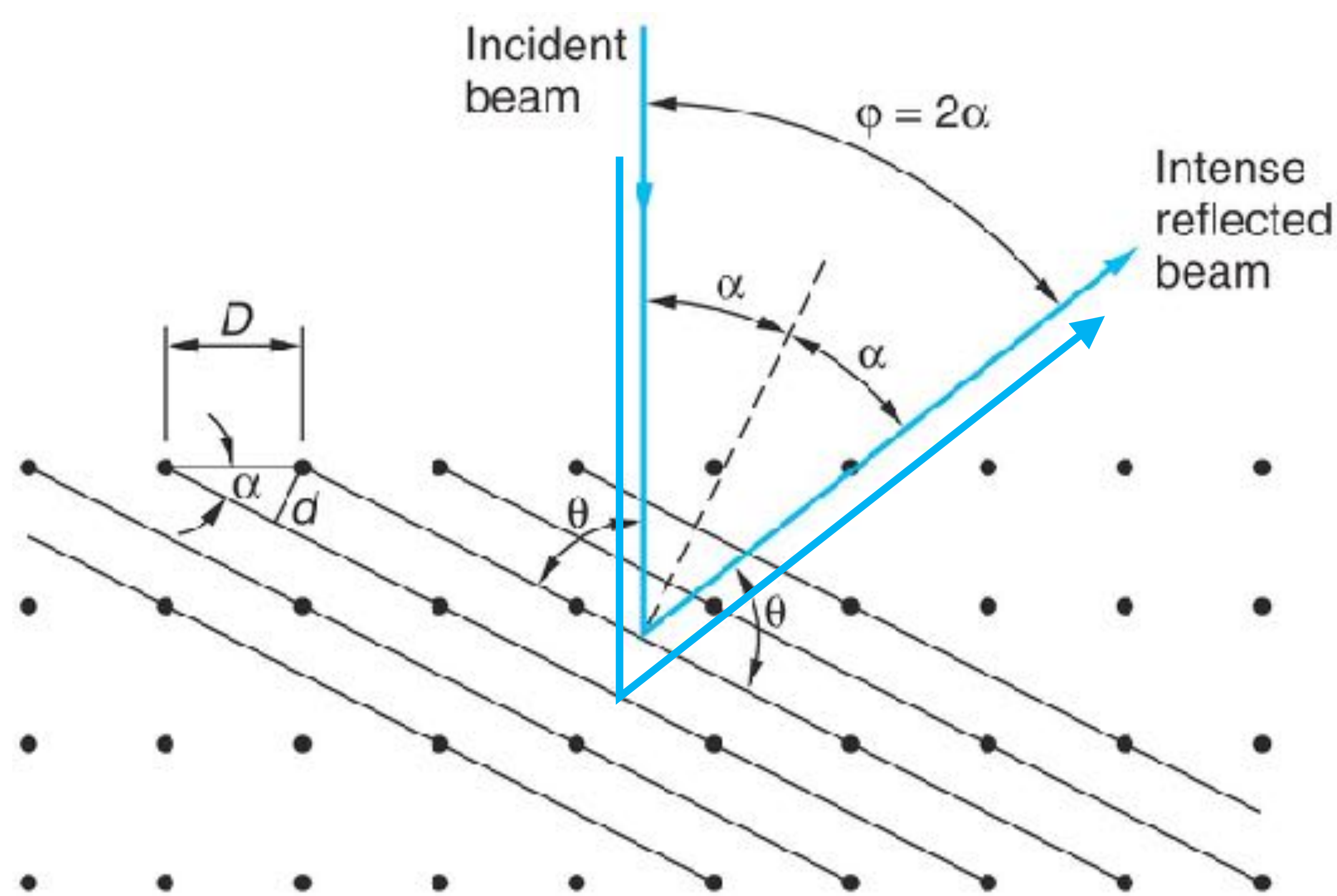


Bragg Scattering:

$$n\lambda = 2d\sin\theta$$

Davisson-Germer:

$$n\lambda = D\sin\varphi$$



Starting with the Bragg formula show that the formula we used in the Davisson-Germer experiment is the same.

Davisson-Germer: $n\lambda = D \sin\varphi$

Bragg Scattering: $n\lambda = 2d\sin\theta$

from Bragg Scattering:

$$n\lambda = 2d\sin\theta = 2d\cos\alpha$$

The relationship between D and d is

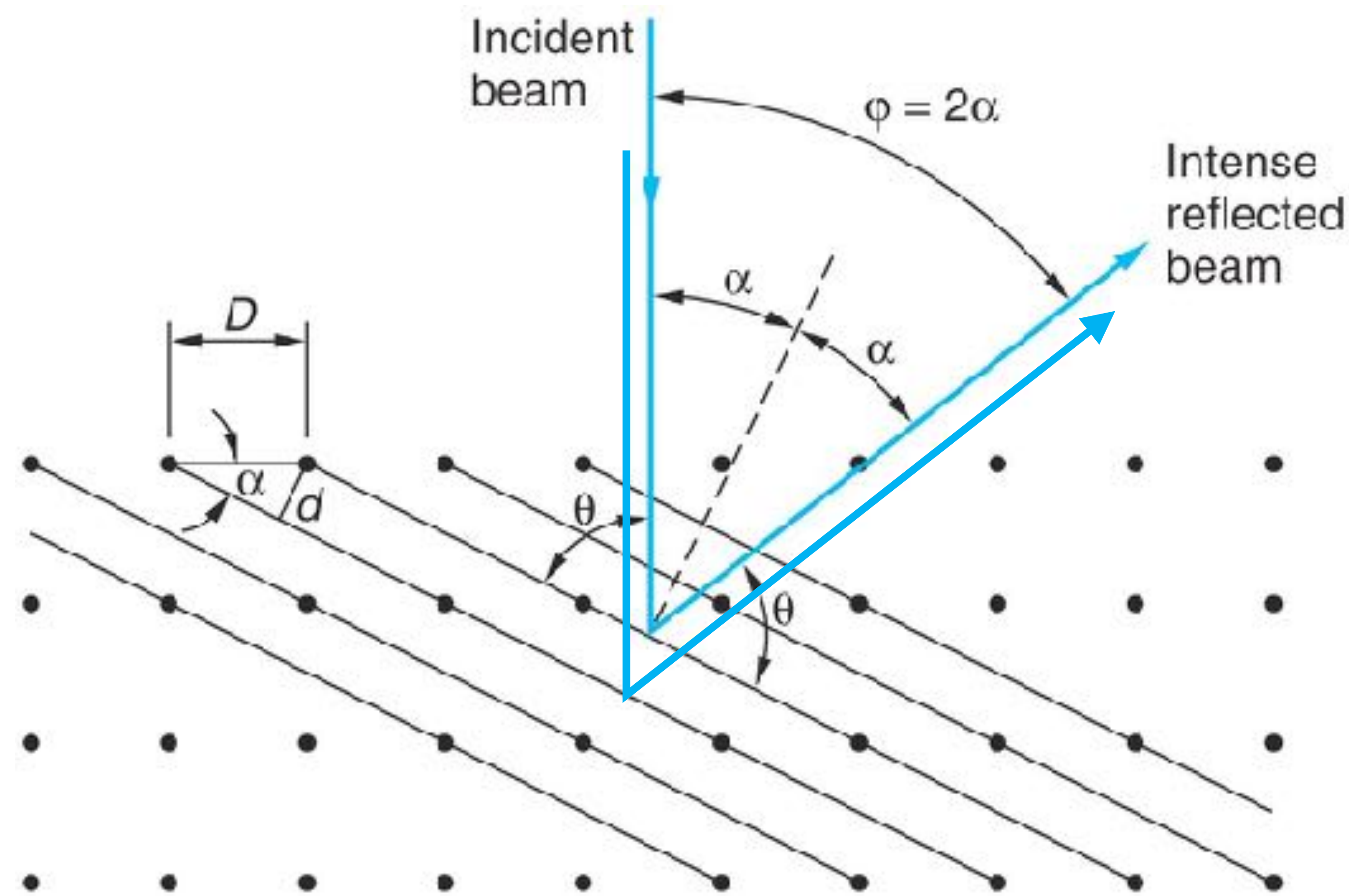
$$d = D\sin\alpha$$

Thus,

$$n\lambda = 2D\sin\alpha\cos\alpha$$

$$n\lambda = D\sin 2\alpha$$

$$\boxed{n\lambda = D\sin\phi}$$



From Lecture Video: Double Slit Recap

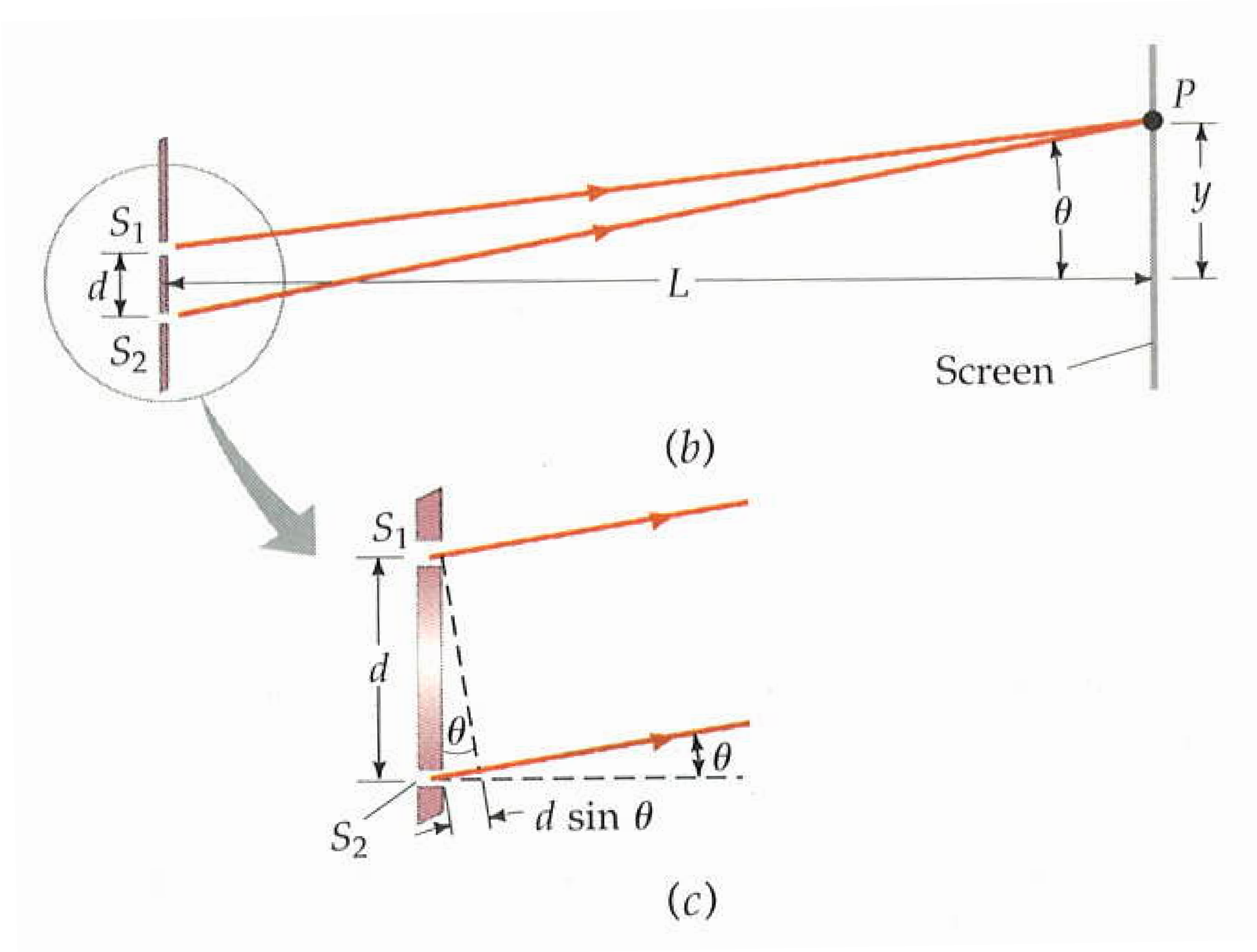
The minima occur at

$$\boxed{d \sin\theta = n\lambda}$$

The distance from the central point to the first fringe is given by

$$\tan\theta = \frac{y}{L}$$

For small θ: $\tan\theta \approx \sin\theta$



Thus,

$$\sin\theta \approx \tan\theta = \frac{y}{L}$$

$$d\sin\theta = d\frac{y}{L} \longrightarrow d\frac{y}{L} = n\lambda \longrightarrow \boxed{y = n\frac{\lambda L}{d}}$$

Electrons are accelerated through a 20. V potential difference, producing a mono energetic beam. This is directed at a double-slit apparatus with 0.010 nm slit separation. A band of electrons detectors is 10 m beyond the double slit. With only slit 1 open, 100 electrons per second are detected at all detectors. With only slit 2 open, 900 electrons per second are detected at all detectors. Now both slits are open.

A) The first minimum in the electron count occurs at detector X. How far is it from the center of the interference pattern?

From the double-slit experiment:

$$n\lambda = d\sin\theta \quad\longrightarrow\quad \frac{1}{2}\lambda = d\frac{y}{L} \quad\longrightarrow\quad y = \frac{L\lambda}{2d}$$

We know that the relationship between accelerating potential, kinetic energy and the deBroglie wavelength give

$$V = \frac{h^2}{2mq\lambda^2} \quad\longrightarrow\quad \lambda = \frac{h}{\sqrt{2mqV}}$$

Putting it together yields:

$$y = \frac{Lh}{2d\sqrt{2mqV}} \quad = \frac{(10\ m)(6.63\times10^{-34}\ J\cdot s)}{2(0.010\times10^{-3}\ m)\sqrt{(2)(9.11\times10^{-31}\ kg)(1.6\times10^{-19}\ C)(20\ V)}}$$

$$\boxed{y = 0.14\ mm}$$

Electrons are accelerated through a 20. V potential difference, producing a mono energetic beam. This is directed at a double-slit apparatus with 0.010 nm slit separation. A band of electrons detectors is 10 m beyond the double slit. With only slit 1 open, 100 electrons per second are detected at all detectors. With only slit 2 open, 900 electrons per second are detected at all detectors. Now both slits are open.

B) How many electrons per second will be detected at the center detector?

The waves from the slits add equally at this point of constructive interference. Hence,

$$|\Psi_T|^2 = (\Psi_1 + \Psi_2)^2 \propto (\sqrt{100} + \sqrt{900})^2$$

$$\boxed{|\Psi_T|^2 \propto 1600\ s^{-1}}$$

Electrons are accelerated through a 20. V potential difference, producing a mono energetic beam. This is directed at a double-slit apparatus with 0.010 nm slit separation. A band of electrons detectors is 10 m beyond the double slit. With only slit 1 open, 100 electrons per second are detected at all detectors. With only slit 2 open, 900 electrons per second are detected at all detectors. Now both slits are open.

C) How many electrons per second will be detected at detector X?

At the point of destructive interference:

$$|\Psi_T|^2 = (\Psi_1 - \Psi_2)^2 \propto (\sqrt{100} - \sqrt{900})^2$$

$$\boxed{|\Psi_T|^2 \propto 400\ s^{-1}}$$

The End (for today)!