Davisson – Germer experiment

Announcements:

- Homework set 7 is due Wednesday.
- Problem solving sessions M3-5, T3-5.
- The 2nd midterm will be April 7 in MUEN E0046 at 7:30pm.

BFFs: Davisson and Germer.

Today we will go over the Davisson-Germer experiment.

Particles with mass can also have a wavelength

For photons we know how to relate momentum and wavelength

Combined (and proven by Compton effect): $p_\gamma = h / \lambda$

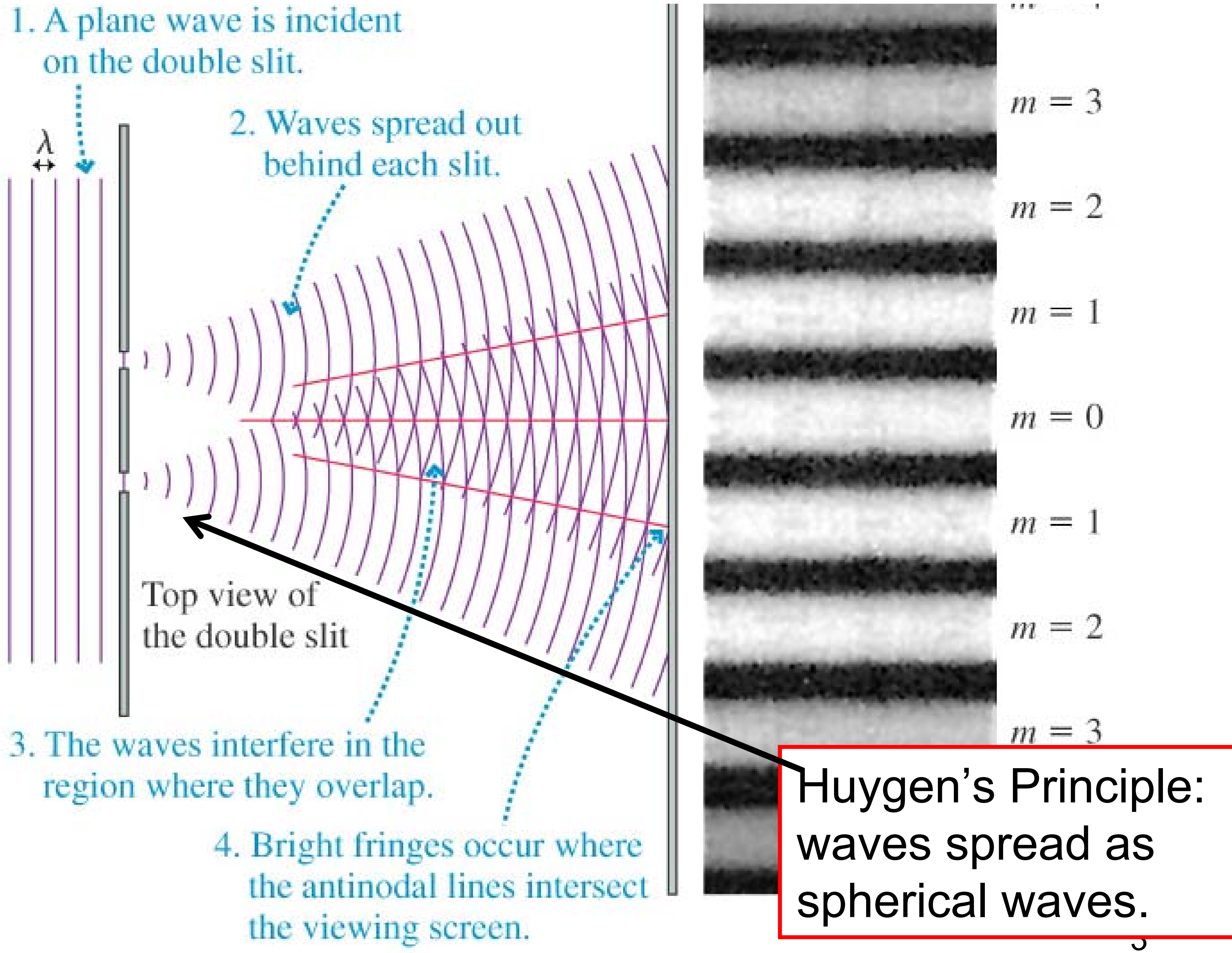
de Broglie proposed the same relationship for massive particles

The de Broglie wavelength: $\lambda = h / p$

Supposing the hydrogen atom electron is a standing wave with this wavelength leads to quantization of angular momentum and energy in agreement with the Bohr model.

But we want more proof that an electron is a wave.

Two slit interference with light



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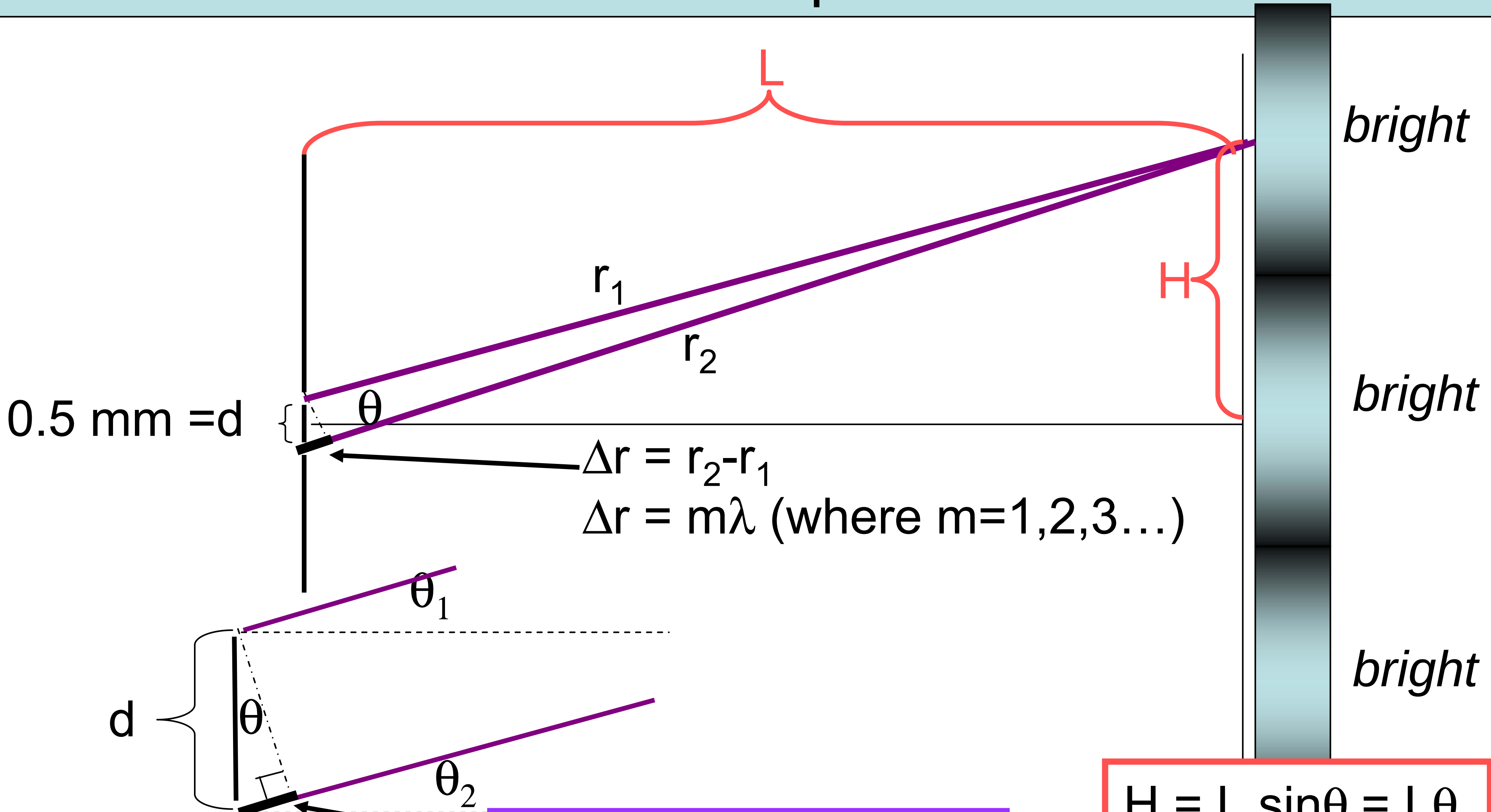
Double-slit experiment



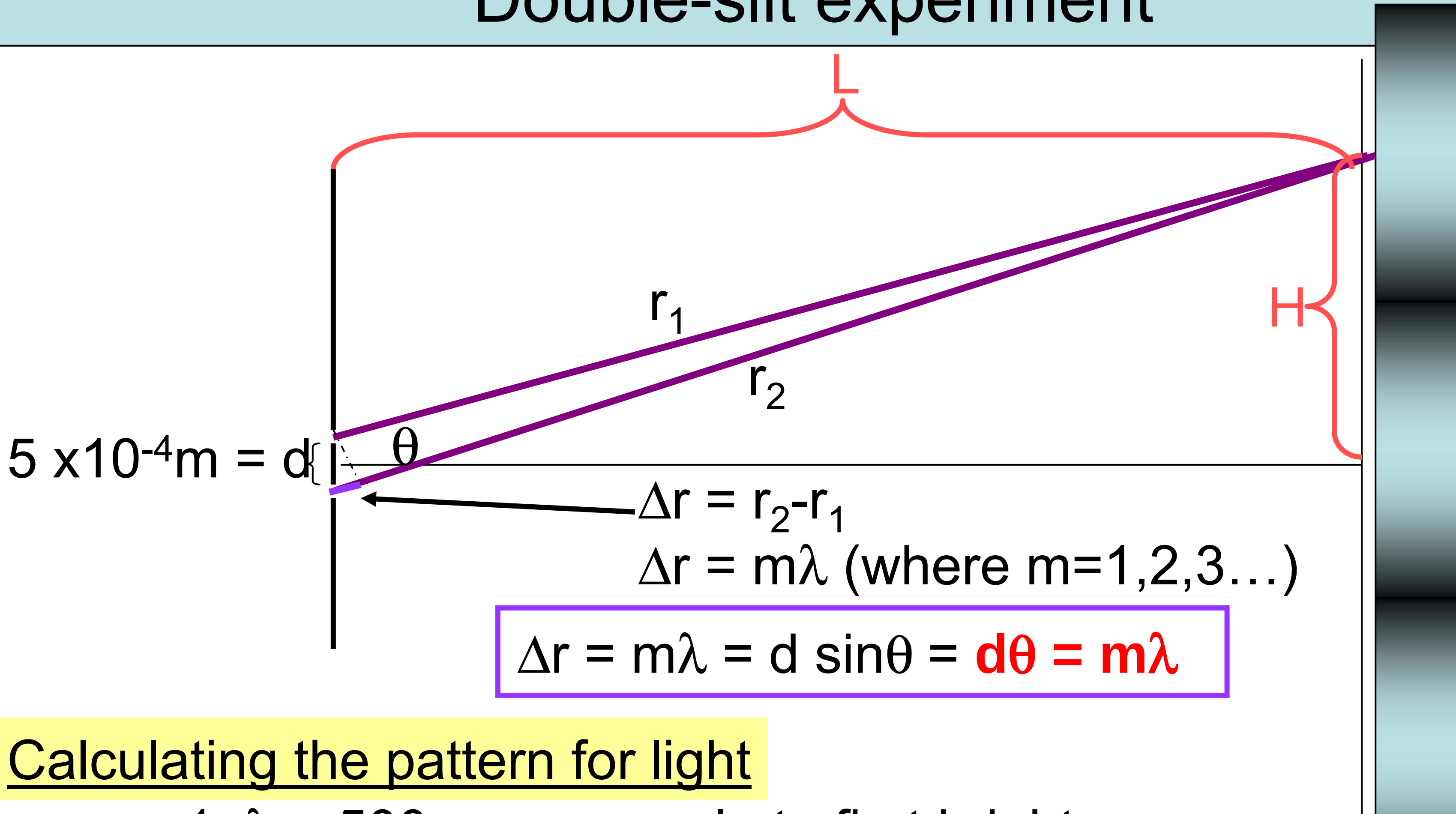
$$H = L \sin\theta = L\theta$$

$$\Delta r = d \sin\theta = d\theta = m\lambda$$

Screen far away so $\theta_1 \sim \theta_2 \sim \theta$ & small angle approx: $\sin\theta = \theta$

$$H = \frac{mL\lambda}{d}$$

Double-slit experiment



$\Delta r = m\lambda = d \sin\theta =$ **$d\theta = m\lambda$**

$H = L\theta$

Calculating the pattern for light

m = 1, λ = 500 nm, so angle to first bright

$\theta = \lambda/d = 500 \times 10^{-9}/(5 \times 10^{-4}) = 0.001$ rad

if L = 3 m, then H = 3 m x 0.001 = 3 mm.

So what will the pattern look like with electrons?

Energy and momentum relationships

Massless particles (photons):

$$E = pc = hc/\lambda$$

$$p = E/c = h/\lambda$$

$$\lambda = h/p = hc/E$$

Visible light photons:

$$E = 2.5\,\text{eV} = 4.0\times 10^{-19}\ \text{J}$$

$$p = 2.5\,\text{eV}/c = 1.3\times 10^{-27}\ \text{kg}\cdot\text{m/s}$$

$$v = c = 3\times 10^{8}\ \text{m/s}$$

$$\lambda = 500\ \text{nm}$$

Massive particles (electrons):

$$K = \tfrac{1}{2}mv^2 = \frac{p^2}{2m} = \frac{h^2}{2m\lambda^2}$$

$$p = \sqrt{2mK} = h/\lambda$$

$$\lambda = h/p = h/\sqrt{2mK}$$

Low energy electrons:

$$K = 25\,\text{eV} = 4.0\times 10^{-18}\ \text{J}$$

$$p = 5055\,\text{eV}/c = 2.7\times 10^{-24}\ \text{kg}\cdot\text{m/s}$$

$$v = 3\times 10^{6}\ \text{m/s} = 0.01\,c$$

$$\lambda = 0.25\ \text{nm}$$

Clicker question 1

Set frequency to DA

The lowest energy (useful) electrons are around 25 eV. We just found these electrons have a wavelength of 0.25 nm. If we use the same two slits as for visible light (d = 0.5 mm), how far apart are the m=0 and m=1 maxima on a screen 3 m away?

A. 3 mm
B. 1.5 mm
C. 3 μm
D. 1.5 μm
E. 3 nm

$\Delta r = m\lambda = d \sin\theta = d\theta = m\lambda$

$H = L \sin\theta = L\theta$

$$H = \frac{Lm\lambda}{d} = \frac{(3\,\text{m})(1)(0.25\,\text{nm})}{0.5\,\text{mm}} = 1.5\,\mu\text{m}$$

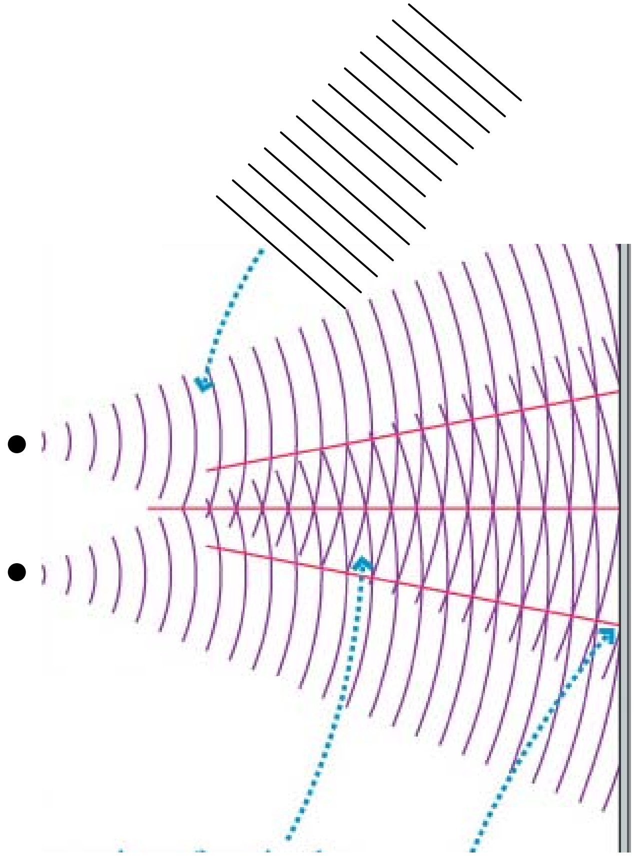
The wavelength of these electrons (0.25 nm) is 2000 times smaller than visible light (500 nm) so the angle and interference spacing is 2000 times smaller for the same slit spacing.

This is too small to see. Need slits that are much closer.

Clue comes from X-ray diffraction…

Using atoms for slits

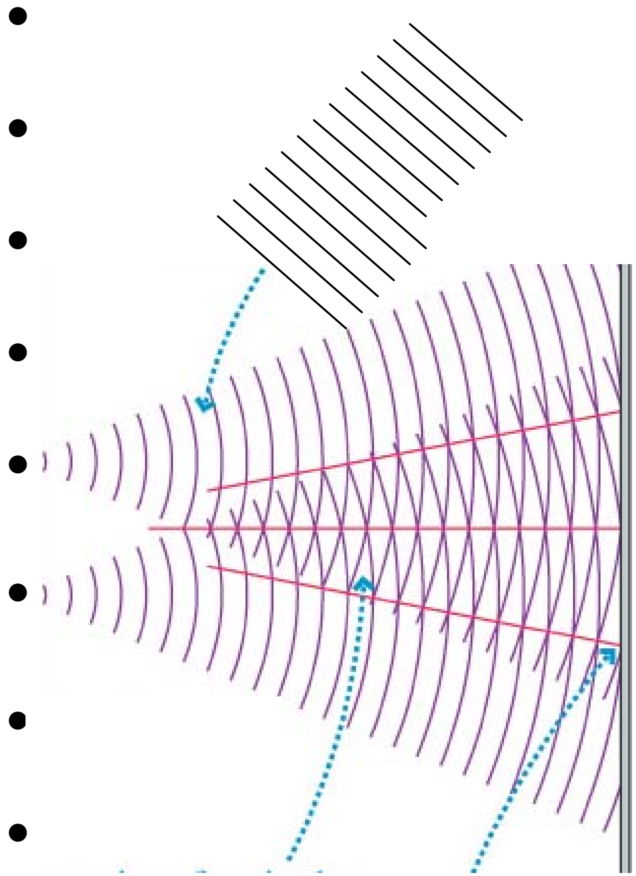
Brilliant idea: Two slits are just two sources.



Hard to get two sources the size of an atom.

Easy to get two objects that **scatter** electrons that are the size of an atom!

Using atoms for slits



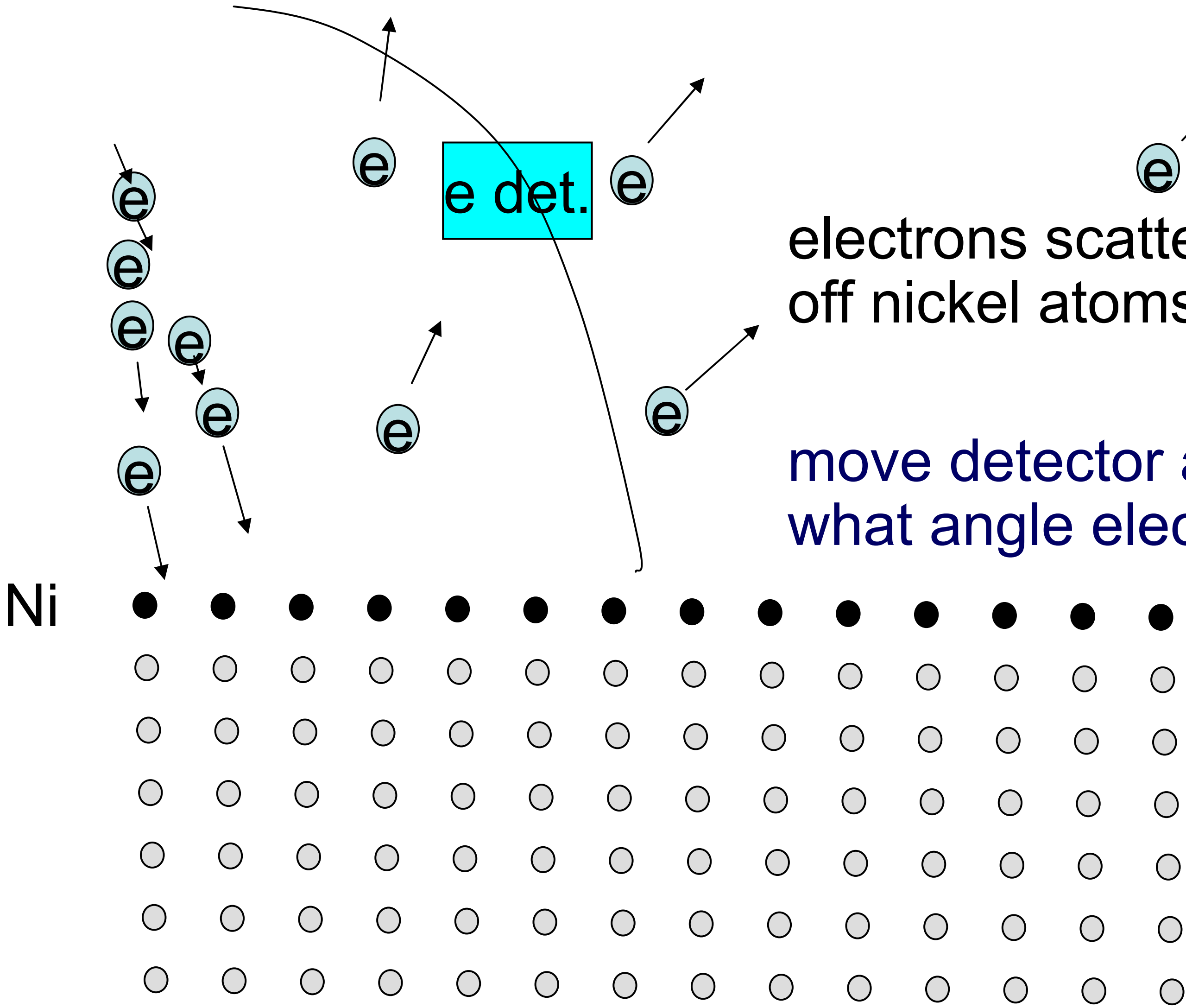
It is difficult to get ***just*** two atoms next to each other.

But multiple equally separated atoms are easy (crystal lattice) and work even better.

Just like reflection diffraction grating discussed for X-ray diffraction.

Davisson – Germer experiment

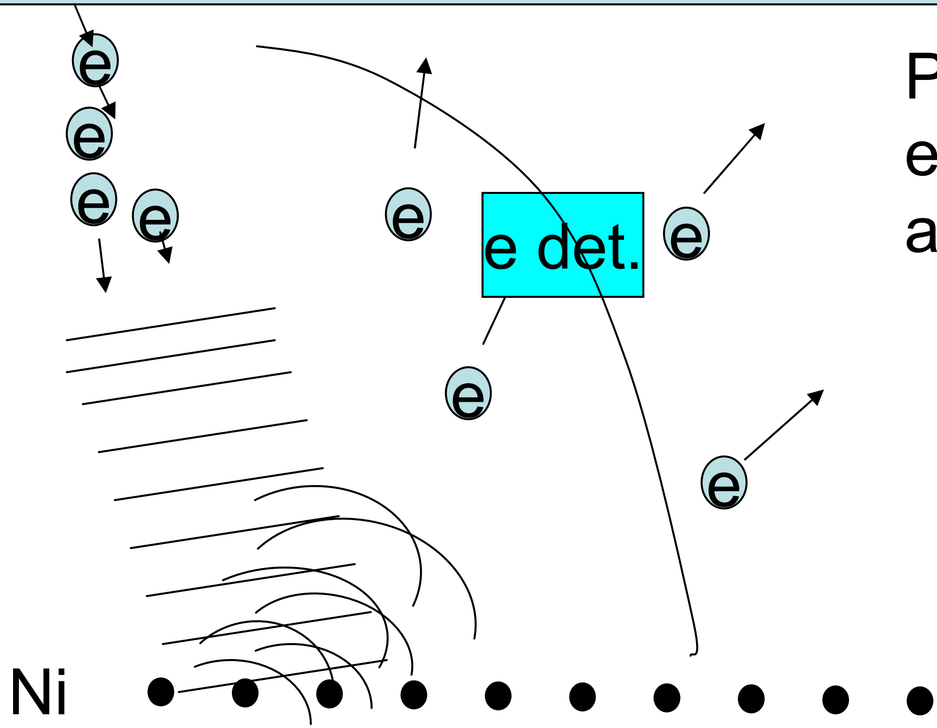
Interference from electron scattering off very clean nickel surface.



electrons scatter off nickel atoms

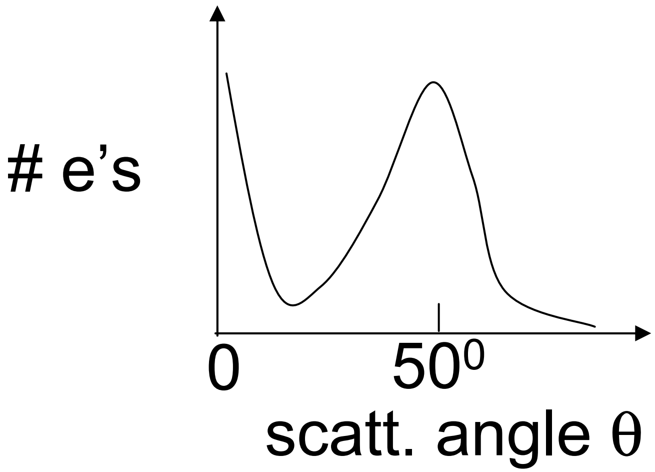
move detector around and see what angle electrons come off

Davisson – Germer results



Plot the results for number of electrons versus scattering angle and find…

A peak!

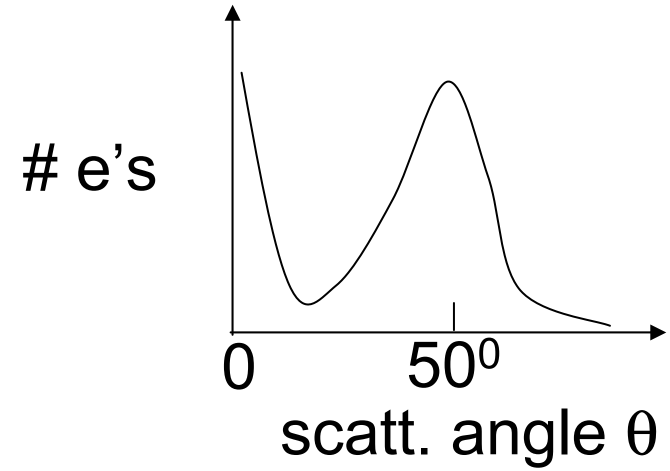


So the probability of finding an electron at a particular angle is determined by the interference of de Broglie waves!

Clicker question 2

Set frequency to DA

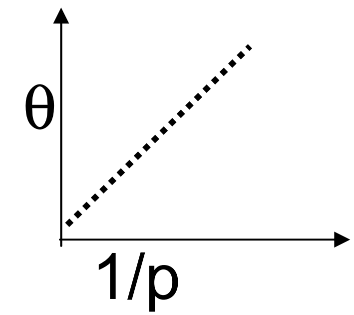
To further prove the de Broglie wave hypothesis, they increased the electron energy. If de Broglie's theory is correct, what will happen?



A. The peak will get larger
B. The peak will get smaller
C. The peak will shift to smaller angle
D. The peak will shift to larger angle
E. Nothing will happen.

$\lambda = h/p$ $\quad d\theta = m\lambda$

Increasing energy increases momentum which decreases the angle $\theta = \frac{m\lambda}{d} = \frac{mh}{pd}$

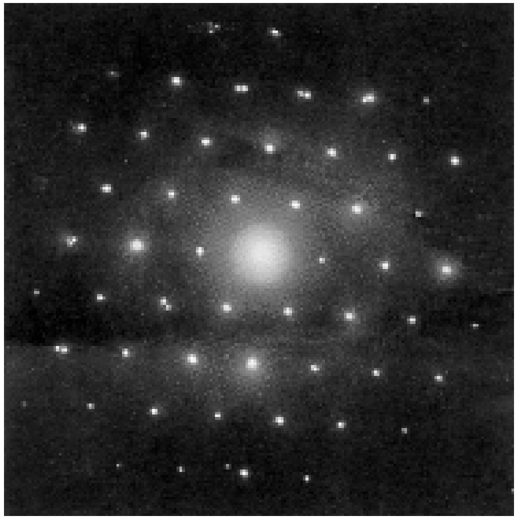


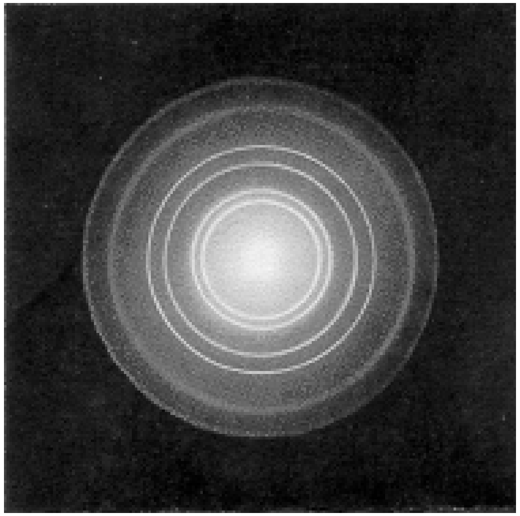
Davisson – Germer tried this as well and it worked.

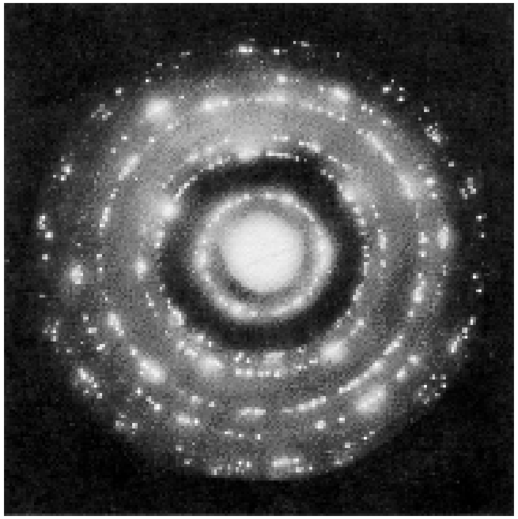
More on matter waves

Two slit interference has been seen with electrons, protons, neutrons, atoms, and in just the last decade with Buckyballs which have 60 carbon atoms.

Electron diffraction, like X-ray diffraction can be used to determine the crystal structure of solids







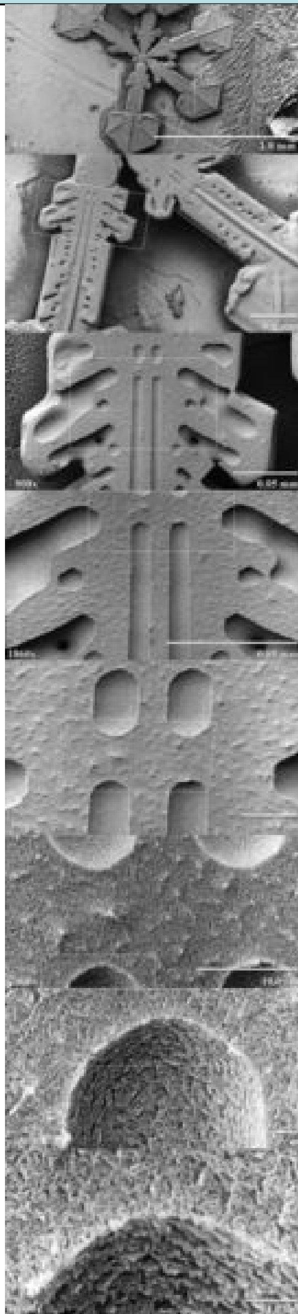
Points come from a regular crystal. Rings come from many crystals randomly arranged.

Electron microscope

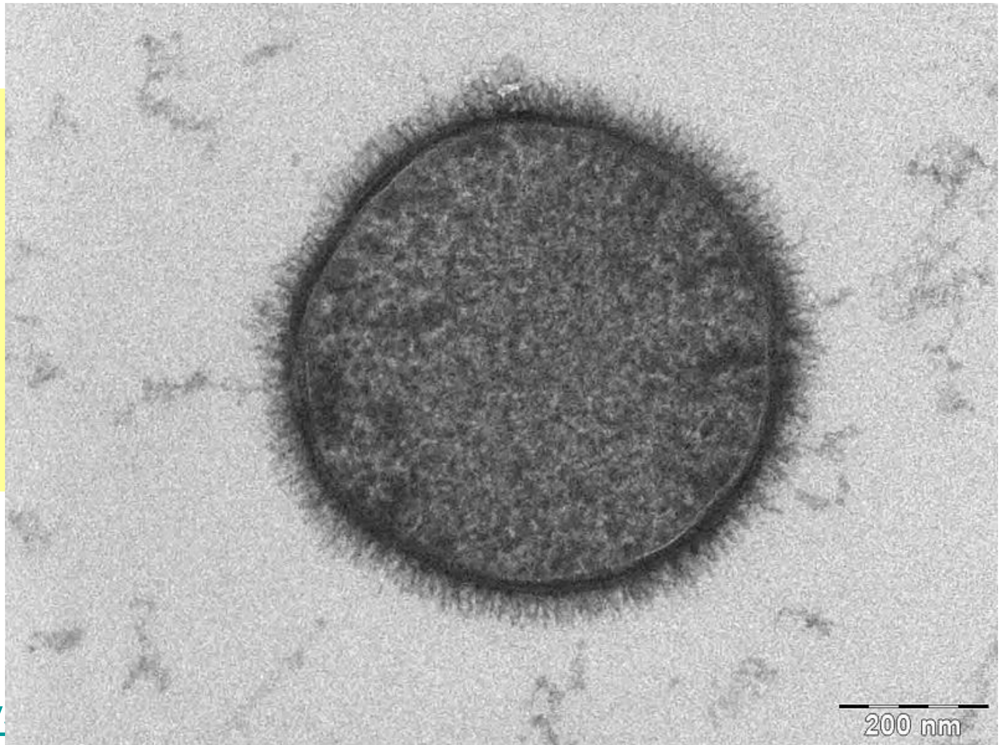
Microscopes limited by the wavelength of light so visible light microscopes cannot resolve objects < 500nm.

Electrons have much smaller wavelengths so get better resolution from *electron microscopes*.

Scanning electron microscope reflects off the surface (for example of snow flakes)



A *Transmission electron microscope* sends electrons through thin samples



http://www.colorado.edu/phy