LECTURE 6: The Franck-Hertz Experiment, de Broglie's Hypothesis, and the Davisson-Germer Experiment

Goal of the lecture: to introduce the idea that matter can exhibit wave properties and learn how this was experimentally confirmed

What I expect you to learn:

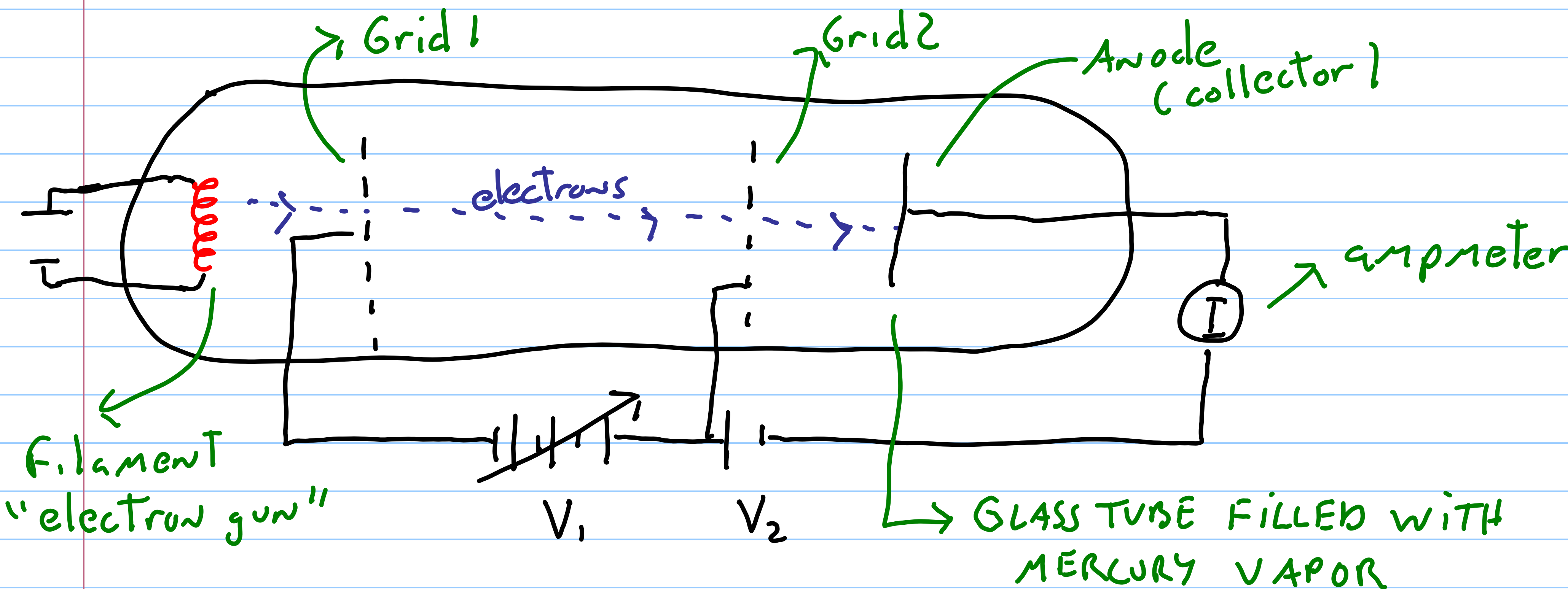
- how to describe the Franck-Hertz experiment and its results
- what is de Broglie's hypothesis
- how to describe the Davisson-Germer experiment
- how to calculate the de Broglie wavelength of the electron

Corresponds to pages 31-33 and 38-44 of textbook

THE FRANCK HERTZ EXPERIMENT

We've seen that the bound-state energies of atoms are quantised. The energy quantisation of atoms was confirmed directly by J. Franck and G. Hertz in 1914.

This experiment goes beyond inducing changes in the energy levels using photons: we bombard atoms with electrons. (PHY 225 Expt.)



FRANCK-HERTZ (CONT.)

WHAT HAPPENS TO THE ELECTRONS EMITTED BY THE FILAMENT?

→ acquire kinetic energy $\frac{mv^2}{2} = eV_1$

A → with no Hg in Tube, electrons will get collected on the anode.

→ at the anode electron will have energy $eV_1 - eV_2$
↳ V_2: retarding potential

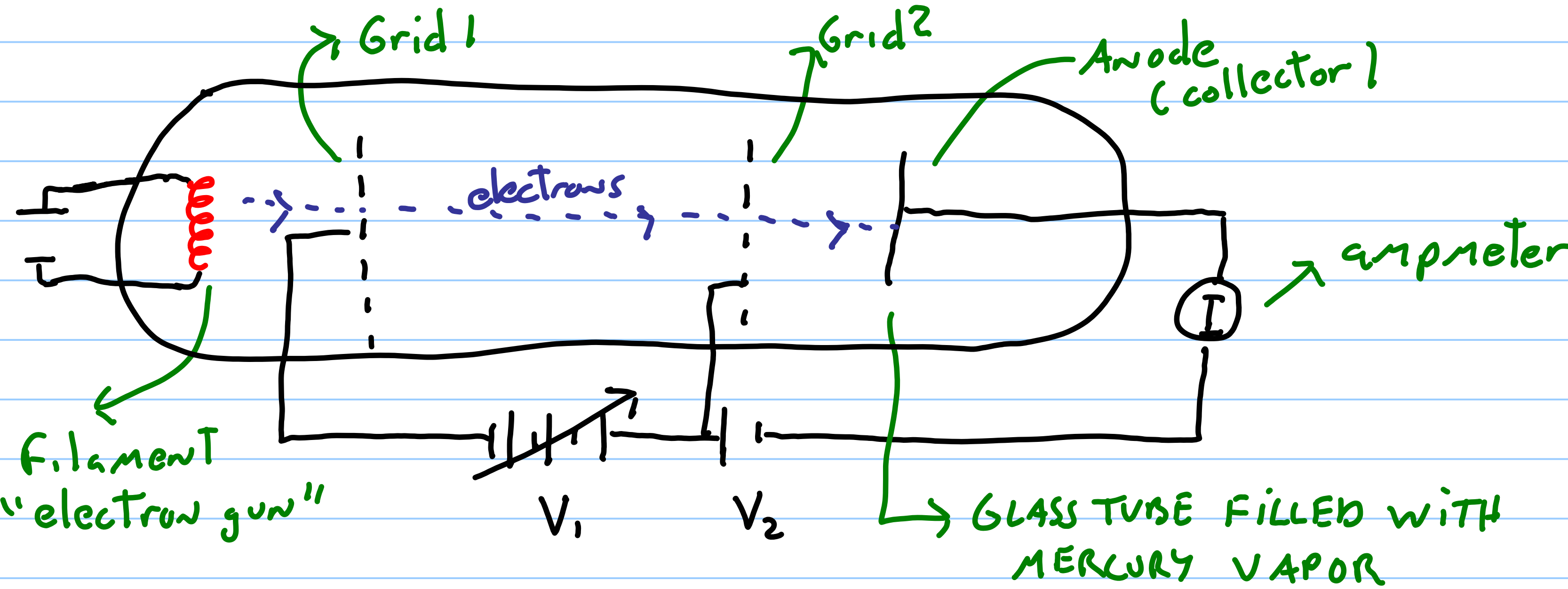
B → with Hg in Tube collisions can occur

→ **elastic:** no energy Transfered ⇒ current not affected (atoms too heavy to gain kinetic energy)

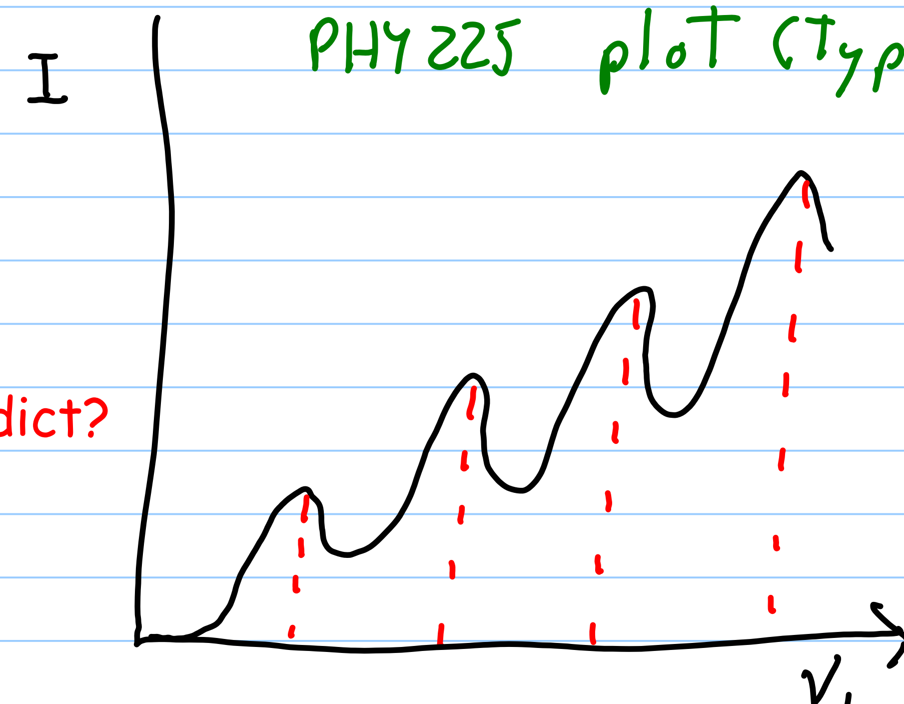
→ **inelastic:** energy is transfered ⇒ Hg excited to higher internal energy

⇒ **electron loses energy**

FRANCK-HERTZ (CONT.)



→ PLOT I vs V_1

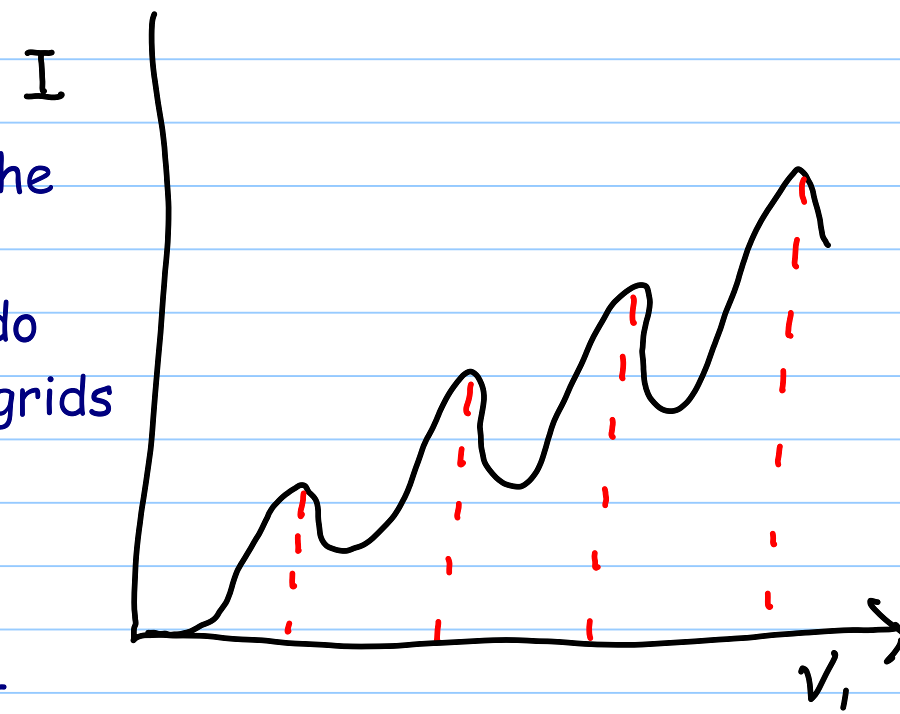


Questions:

- Why does I increase?
- What does classical physics predict?
- How do you explain the dips?

FRANCK-HERTZ EXPERIMENT (cont.)

The first dip will occur when electrons acquire just enough energy to excite the Hg atoms to a state of higher internal energy. The electrons need ~5 eV to do that. So the voltage between the two grids has to be ~5 Volts (a bit more due to retarding potential).



The eye does not see 5 eV photons but Franck and Hertz confirmed that Hg emits radiation of that energy (corresponds to ~250 nm)

It can also be shown that when sufficient energy is available to ionise an atom, the energy of the ejected electron can take any positive value:

- -discreet negative energies corresponding to bound states
- -a continuum of positive energies for free electrons

De Broglie's Hypothesis

We've seen before that em radiation exhibits particle characteristics

This dual nature was accepted (though not understood) at the beginning of the 1920s.

Matter was believed to exhibit only particle characteristics

Around that time, Louis de Broglie hypothesised that particles could have wave-like properties:

For photons: $E = h\nu$, $p = h/\lambda$

Apply it to matter: $\nu = \frac{E}{h}$, $\lambda = h/p$

λ = de Broglie wavelength

de Broglie hypothesis (cont.)

For the Bohr atom the electron in a stable orbit must be a **standing wave**

since $\lambda = \frac{h}{p}$, $L = mvr = pr$

$\Rightarrow L = \frac{h}{\lambda} r$ and $n\lambda = 2\pi r$

we have: $L = \frac{nh}{2\pi} = n\hbar$

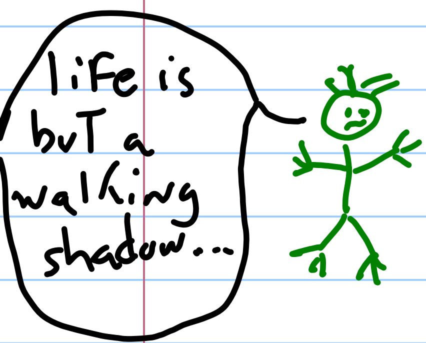
↳ This is what Bohr postulated!

this provides a qualitative explanation of the stability of the Bohr atom

In non-relativistic limit: $p = mv$ $\Rightarrow \lambda = \frac{h}{mv}$

de Broglie's hypothesis (cont)

<u>Example</u>: de Broglie wavelength of a student:



→ mass = 66 Kg

→ velocity = 1 m/s , $p = mv = 66$ Kg m/s

$$\lambda = \frac{h}{66} = \frac{6.6 \times 10^{-34}}{66} = 1 \times 10^{-35}\ m$$

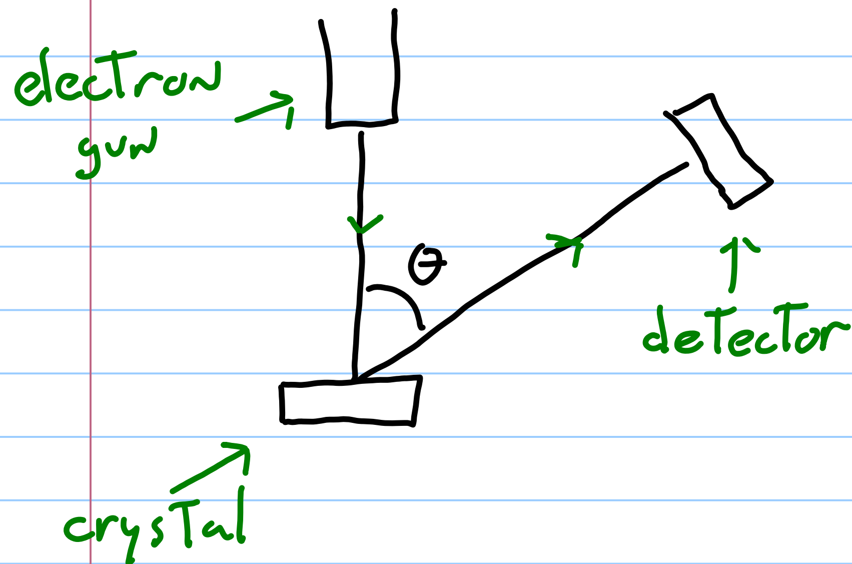
10^{-35} m is small... hard to do interference experiments with students (grating hard to find)

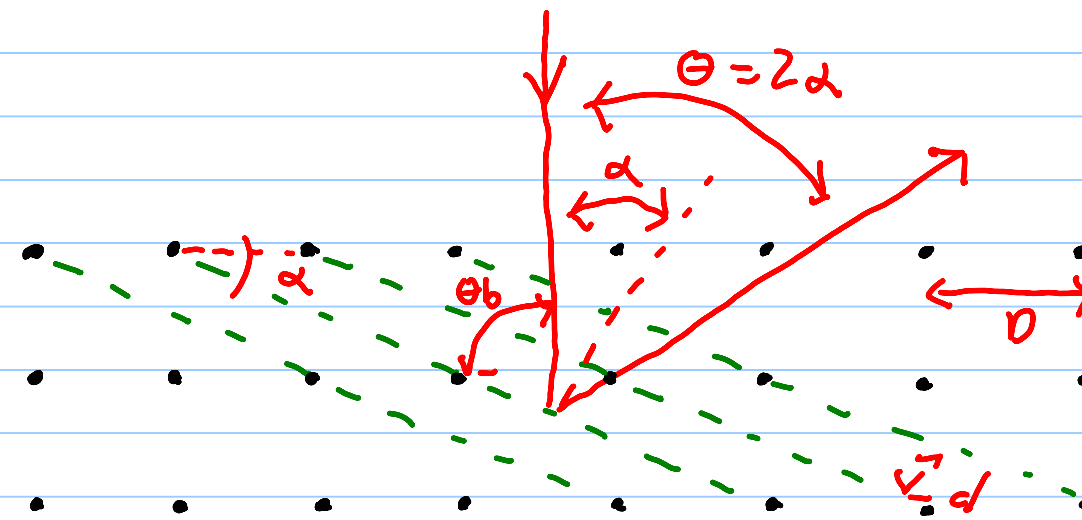
Electrons however: $\frac{mv^2}{2} = eV$ ⇒ wavelengths comparable to X-Rays if $E_{kin} \simeq 1 - 1000$ eV

⇒ gratings available...

WAVE-LIKE BEHAVIOUR OF ELECTRONS

DAVISSON - GERMER EXPERIMENT



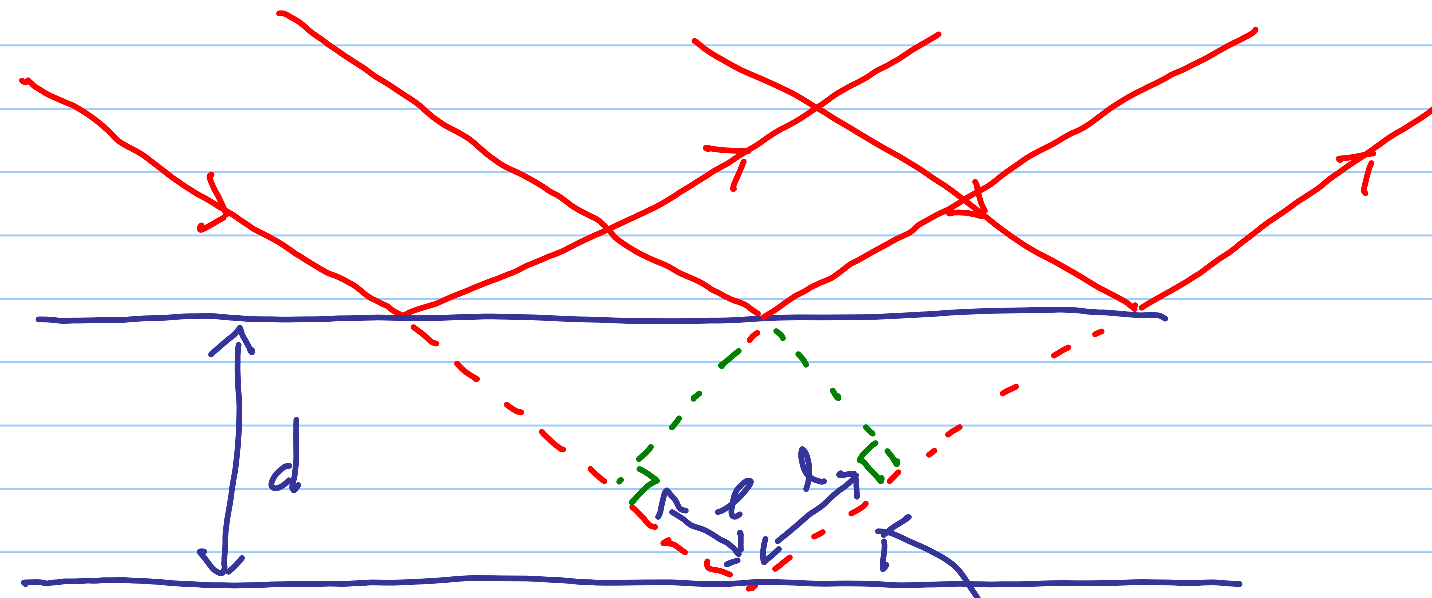


Bragg condition: $n\lambda = 2d \sin\Theta_b$

$d = D \sin\alpha$, $\alpha = \pi/2 - \Theta_b$, $\Theta = 2\alpha$

$\Rightarrow \quad n\lambda = D \sin\Theta$

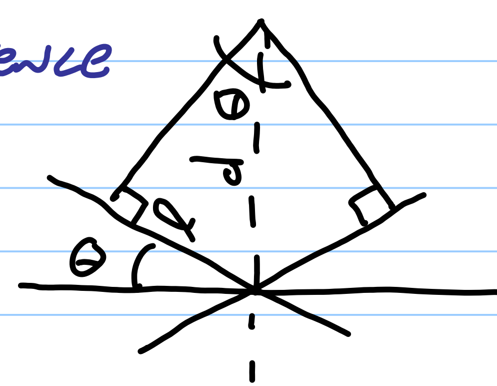
BRAGG CONDITION INTERLUDE:



$\ell = d \sin\theta$

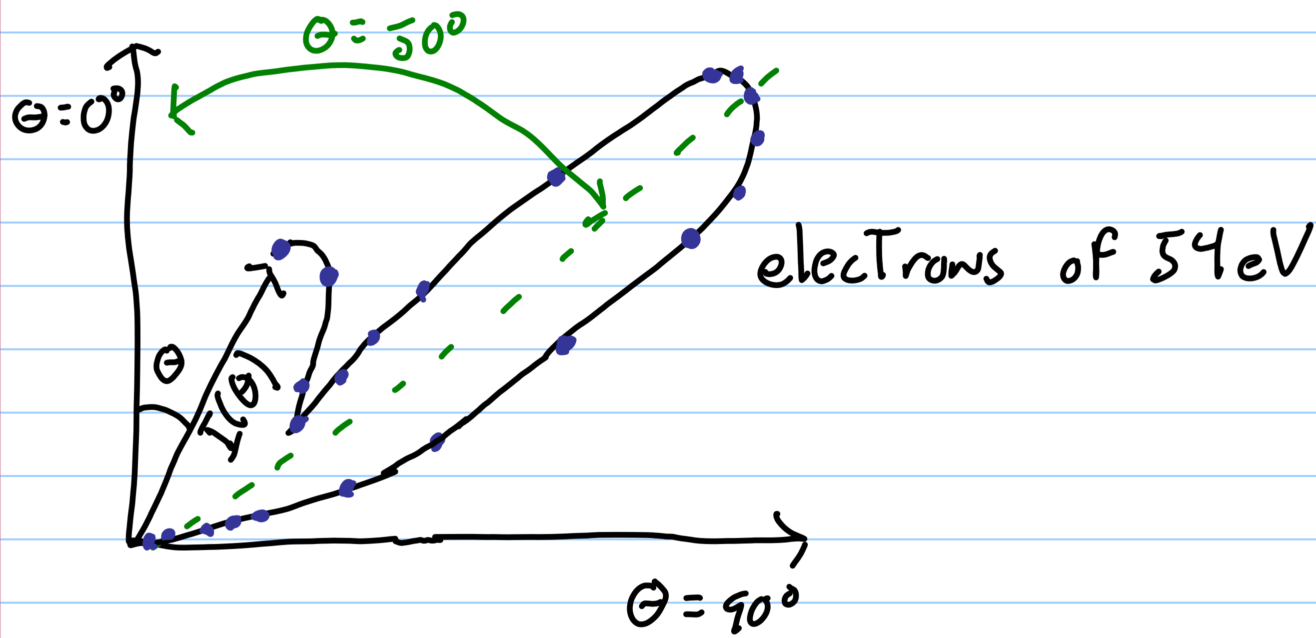
extra pathlength: $2\ell = 2d\sin\theta$

$n\lambda = 2d\sin\theta \Rightarrow$ const. interference



DAVISSON - GERMER (cont.)

RESULTS:



MAXIMUM INTENSITY FOUND AT 50°

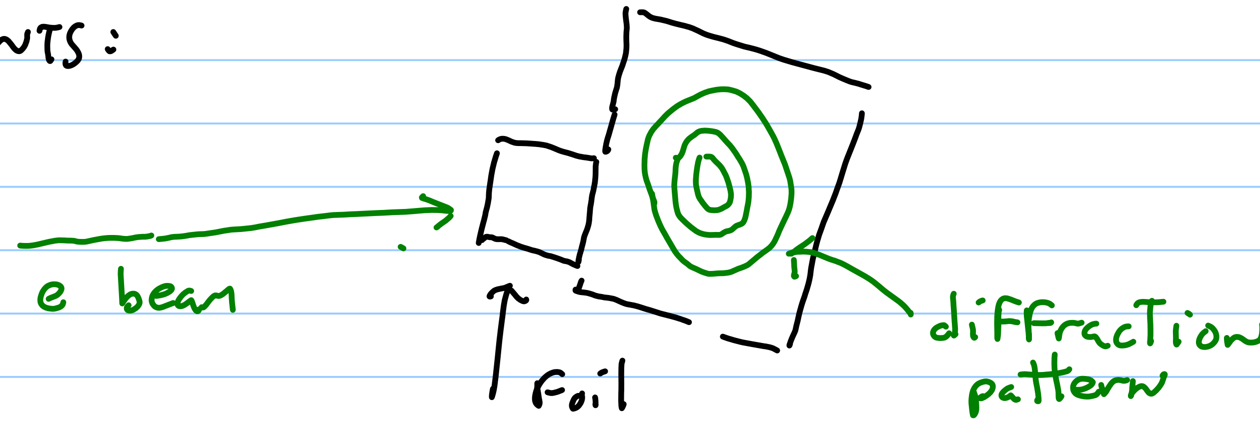
→ SPACING OF CRYSTAL WAS KNOWN ⇒ $\lambda_e = 1.65$ Å

de Broglie λ_e for electron of 54 eV = 1.67 Å

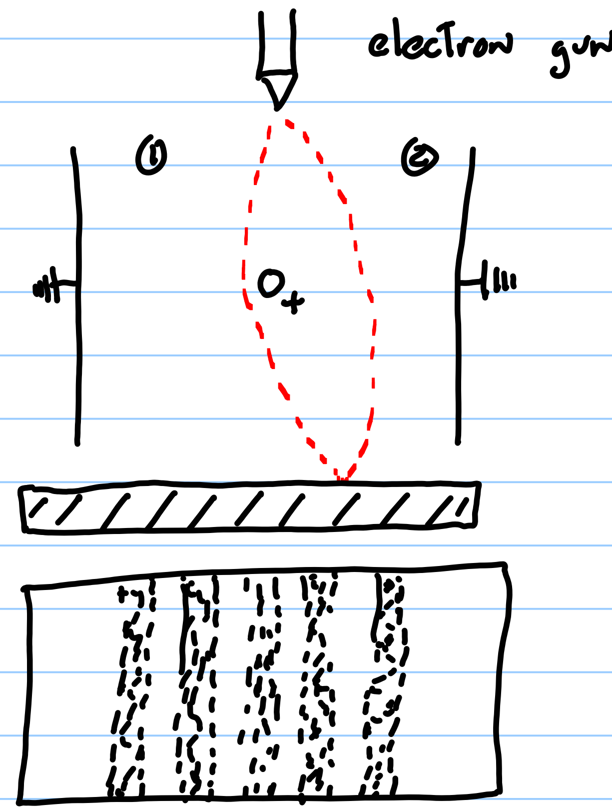
de Broglie's Hypothesis (cont.)

OTHER EXPERIMENTS:

- G.P. THOMSON



- Tonomura's biprism
  → See lecture 2



PROBLEM SET #1

Textbook problems: 1.6, 1.11, 1.16, 1.29

→ Due Oct 4th