Experiment 3

Electron Diffraction

3.1 Objectives

- Electrons as waves.
- Study and verification of the de Broglie hypothesis $\lambda = h/p$.
- Measurement of the spacing of diffracting planes in graphite.

3.2 Theory

In a bold and daring hypothesis in his 1924 doctoral dissertation Louis de Broglie reasoned that if electromagnetic radiation can be interpreted as *both* particles (Photoelectric Effect, Compton Scattering) and waves (diffraction), then perhaps the electron, which had traditionally been interpreted as a particle, could also have a wave interpretation. De Broglie hypothesized that *all particles* have a wave behavior with a universal relationship between the wavelength and momentum given by $\lambda = h/p$. This expression is called the de Broglie relationship and the wavelength is called the de Broglie wavelength. The momentum in this relationship is the momentum that is conserved in collisions, i.e. the relativistic momentum. The de Broglie relationship holds for all particles. Note that it is identical to the one for photons ($E = h\nu$).

Diffraction phenomena represent clear evidence for wave properties. *How can an electron be both wave and particle?*

In this experiment you will investigate the diffraction of electrons passing through a thin layer of graphite (carbon), which acts as a diffraction grating. It was Max von Laue, who in 1912 suggested (in connection with x-ray studies) that the basic granularity of matter at the atomic level might provide a suitable grating. Bragg, using the cubic system of NaCl, first calculated the inter-atomic spacings and showed them to be of the

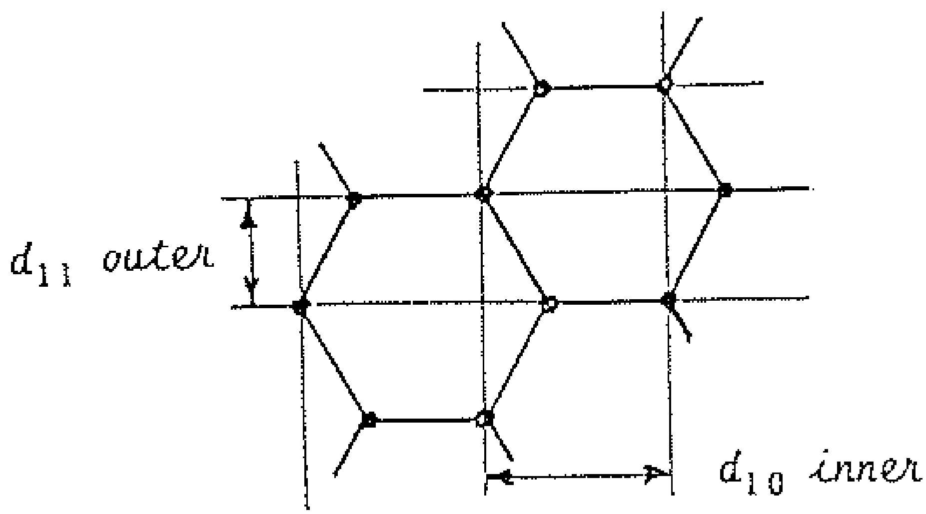

Figure 3.1: Structure of Graphite

right order for x-rays. Fig. 3.1 shows the hexagonal structure of graphite with the two characteristic spacings of 0.123 and 0.213 nm.

3.3 Apparatus

Our electron diffraction tube, see Fig. 3.2, comprises a 'gun' which emits a narrow, converging beam of electrons within an evacuated clear glass bulb on the front surface of which is deposited a luminescent screen. Across the exit aperture of the gun lies a micro-mesh nickel grid, onto which a *very* thin layer (only a few molecular layers!) of graphite has been deposited.
The electron beam penetrates through this graphite target to become diffracted into two rings corresponding to the separation of the carbon atoms of 0.123 and 0.213 nm. The diffraction pattern appears as rings due to the polycrystalline nature of graphite. The source of the electron beam is an indirectly-heated oxide-coated cathode.

3.4 Important Precautions

Due to its extreme thinness the graphite can easily be punctured by current overload. Such current overload causes the graphite target to become overheated and to glow dull

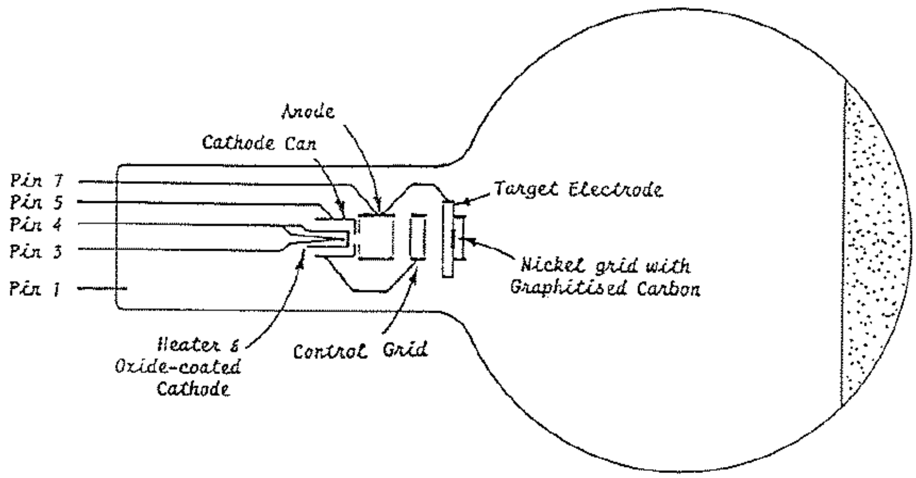

Figure 3.2: Schematic of the Electron Diffraction Tube

red. It is therefore important to monitor the anode current and to keep it below 0.25 mA at all times. Use a handheld digital multimeter. In actuality you will likely find that the current tends to stay well below this value, typically a few μA (micro-Amps). It is also good practice to inspect the target periodically during an experiment.

The 33k resistor R in Fig. 3.3 is incorporated into the filament protection circuit of the stand to provide 'negative auto-bias' and so reduce the likelihood of damage to the target due to accidental abuse. The total emitted current passes through R. Therefore an increase in current causes the cathode-can to become more negatively biased, thereby reducing the emitted current.

3.5 Experimental Procedure

Connect the tube into the circuit shown in Fig. 3.3 **but ignore** V_B. Both heater supply and HV are obtained from the 813 KeV power unit. The HV should be connected to the "+" and "−" HV connections to get the full voltage which is read on the top-scale of the KeV unit's meter. Be sure the high voltage slider is at zero before switching on the unit. Switching on the unit (in back) will also switch on the heater. **IMPORTANT:** Switch on the heater supply (V_F), and wait one minute for the cathode temperature to stabilize before applying the HV (anode voltage V_A).

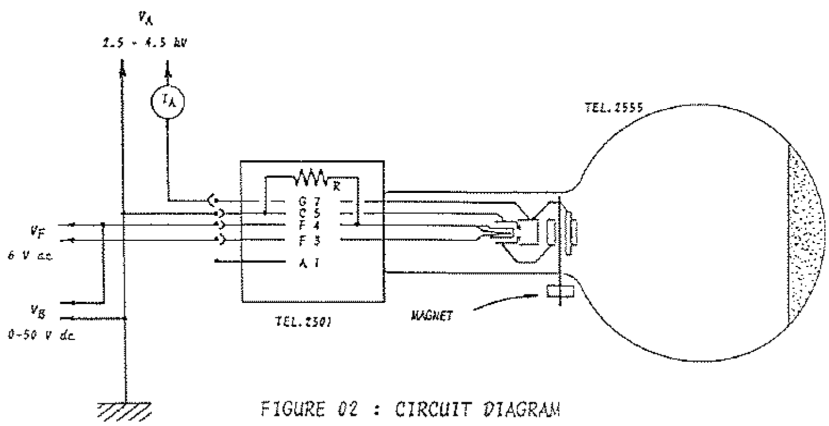

Figure 3.3: Circuit Diagram

3.6 Data Taking and Analysis

The tube is old and rings are faint, so do the best you can. Be sure the room is very dark. The rings are quite distinct at the full 5 kV, but get very hard to see as you go down in voltage. Try to go as low as 2.5 kV. Take at least 10 different data points, measuring the diameter of the two rings with the calipers. You can adjust the position of the spot by using the little magnet on the neck of the tube. You want the rings centered so you can do the correction for the curvature of the tube-face. Do the geometry and correct for the curvature (and thickness?) of the glass (see Figure 3.4). The length L in Figure 3.4 is controlled during production of the tube to be 13.0 ± 0.2 cm.

The kinetic energy and momentum of the electrons are of course related to the accelerating potential. From Fig. 3.4 we also know that $D = 2L\tan\theta$, where D is the *extrapolated* diameter. Show that by using the de Broglie relation, the lattice spacing d is related to the accelerating voltage V_A approximately by,

$$d = \frac{4\pi L\hbar c}{D\sqrt{2eV_A mc^2}} \tag{3.1}$$

Plot D as a function of $V_A^{-1/2}$ for all your data and indicate the estimated error in D as vertical error bars. The straight lines you should get verify the theory and substantiate de Broglie's hypothesis. Also calculate the two values for d from your data (no need to make the above approximation!), and compare with the accepted values of 0.123 and 0.213 nm.

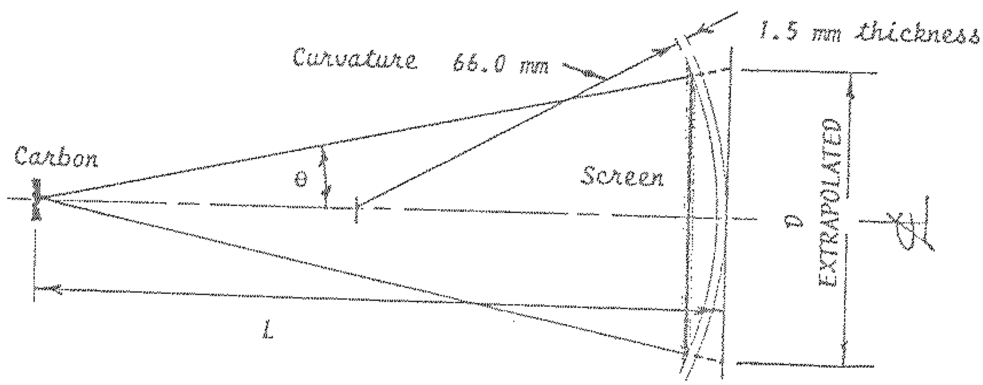

Figure 3.4: Curvature and glass thickness of the electron diffraction tube. The length $L = 13.0 \pm 0.2$ cm.

3.7 References

Any good Modern Physics textbook.