Modern Physics Laboratory
MP6 Electron Diffraction

Purpose

In this experiment, you will study the wave nature of electrons and the powder diffraction pattern of electron waves from a poly-crystalline graphite sample.

Equipment and components

Electron diffraction tube with universal stand, DC power supply, high-voltage power supply, multi-meter, and callipers.

Background

In 1924, French physicist Louis de Broglie proposed that for particles of momentum p, their motion is associated with a wave. The wavelength λ of the matter wave is given by

$$\lambda = \frac{h}{p}, \tag{1}$$

where $h = 6.63 \times 10^{-34}$ J.s is Planck's constant. The first experimental evidence of the existence of matter waves was found by C. Davisson and L.H. Germer[1] in 1927. They 'reflected' slow electrons from a single crystal of nickel and used Bragg's scattering expression to test Eq. (1). Excellent agreement was found.

In this experiment, we will study the wave nature of electrons by measuring their diffraction pattern from a poly-crystalline graphite sample. In the experiment, a beam of electrons is focused and accelerated to a graphite target by a high-voltage power supply. The electron waves are diffracted by the ordered array of carbon atoms, which make up graphite, and form a diffraction pattern. After passing through the graphite sample, the electrons still have sufficient energy and will light up the phosphorous screen when they hit it. In this way, the diffraction pattern of the electrons becomes visible. For electrons passing through an accelerating potential V, their kinetic energy gain is given by, $(1/2)\, mv^2 = eV$, where m is the mass of the electron and e is its charge. The de Broglie wavelength of the electrons then becomes

$$\lambda = \frac{h}{\sqrt{2meV}} \approx \frac{1.23}{\sqrt{V}} \text{ (nm)}. \tag{2}$$

Roughly speaking, the wavelength of electrons is approximately 0.1 nm when they pass through an accelerating potential of 150V.

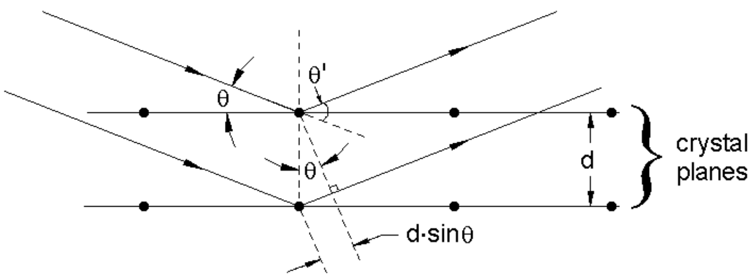
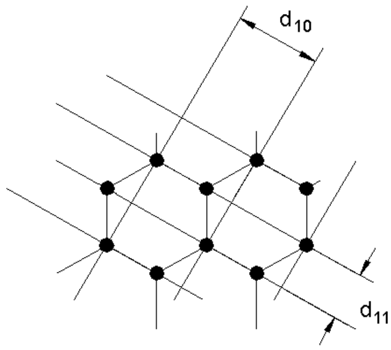


Figure 1 Diffraction of an incident wave by a set of crystal planes

[1] C. Davisson and L. H. Germer, *The scattering of electrons by a single crystal of Nickel*, Nature, April 1927, pp. 558.

Figure 1 shows a typical arrangement for diffraction of an incident wave of wavelength λ by a set of crystal planes with separation *d*. Constructive interference, which produces diffraction peaks, occurs when the difference of the path lengths between the two incident waves is equal to an integer number of wavelengths

$$2d\sin\theta = n\lambda, \qquad n = 1, 2, 3 \ldots \qquad (3)$$



where θ is the diffraction angle.

Figure 2 Crystal structure of graphite showing the two sets of crystal planes

Graphite is made of carbon atoms and has a layered, planar structure. In each layer, the carbon atoms are arranged in a hexagonal lattice, as shown in Fig. 2. The distance between the graphite layers is 0.335 nm. There are two sets of atomic planes for the hexagonal lattice and their spacing is marked as d_{10} and d_{11}, respectively. Diffraction peaks arising from both sets of atomic planes will be observed if the sample is randomly orientated. Because the graphite sample used in the experiment is a powder sample, which is composed of many small crystallites with random orientations, the diffraction peaks for an orientated sample become a *powder pattern* consisting of diffraction rings, which are concentric about the central transmitted (un-diffracted) beam, as shown in Fig. 3(b). The inner ring arises from the atomic planes with separation d_{10} and the outer ring comes from the atomic planes separated by d_{11}.

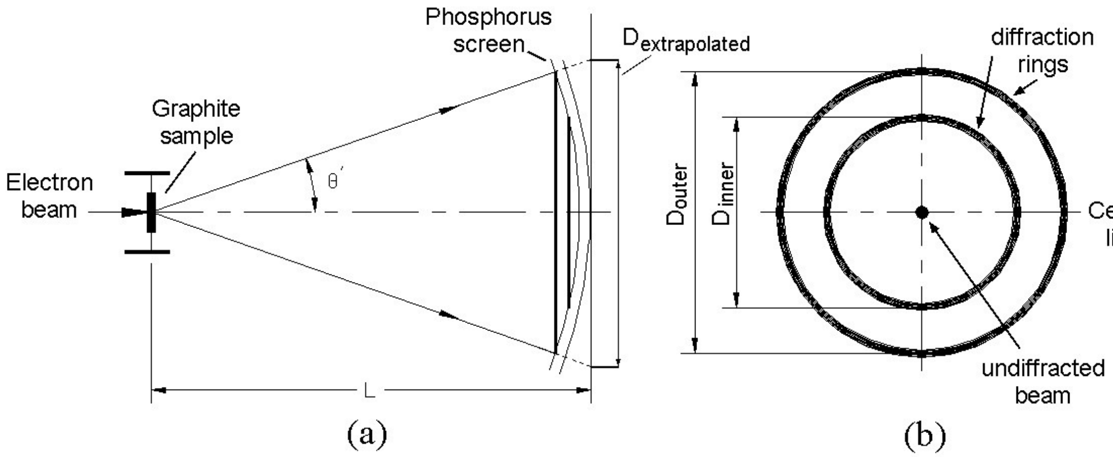


Figure 3 (a) Side view of the electron diffraction tube and (b) Powder pattern of diffraction rings.

Figure 3(a) shows the side view of the electron diffraction tube used in the experiment. A transmission setup is employed in the diffraction tube, in which the angle between the transmitted (un-diffracted) beam and the diffracted beam is measured. As shown in Fig. 3(a), the transmission angle, θ', is related to the diameter *D* of the diffraction ring and the working distance *L* via the equation,

$$\sin\theta' = \tan(\frac{D}{2L}) \approx \frac{D}{2L}. \tag{4}$$

For the diffraction tube used in this experiment, we have L = 13.5 cm. Note that for maximum accuracy, the ring diameter should be extrapolated, as shown in Fig. 3(a), in order to compensate both the curvature and thickness of the glass diffraction tube.

From Fig. 1 we find that the transmission angle θ' = 2θ. For small diffraction angles, Eq. (3) can be rewritten as

$$n\lambda \approx d\theta'. \tag{5}$$

Substitute Eq. (2) into Eq. (5), we find

$$\frac{1}{D} = \frac{d\sqrt{V}}{2.46L}, \tag{6}$$

where d is the interlayer spacing in units of nano-meters.

Procedure

Experimental apparatus

Figure 4 shows the structure of the electron diffraction tube used for this experiment, which consists of an electron gun, a graphite target and a fluorescent screen. With this special vacuum tube, electrons are produced and accelerated and their diffraction pattern by a poly-crystal graphite sample is recorded by the fluorescent screen.

Electron gun

The heated cathode and anode make up the electron gun. Electrons are produced by heating a filament that is located inside an oxide-coated metal "can" called the cathode; they are ejected by thermionic emission from this heated piece of metal. Once emitted, the electrons are accelerated by the anode with an adjustable accelerating potential V_a [2000 - 5000V provided by a kilovolt power supply between the cathode (-) and anode (+)] and form an electron beam.

Carbon target

As the electron beam passes through the anode, it meets a very thin mesh containing vaporized graphite (carbon). The carbon suspension acts as a poly-crystal as described above.

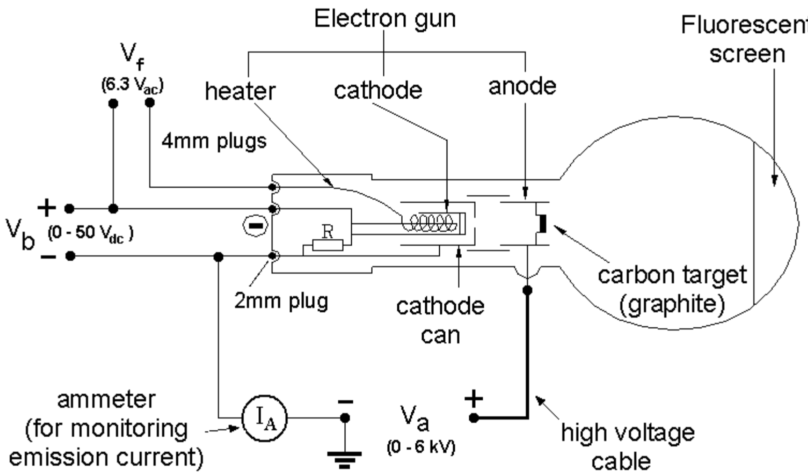


Figure 4 Structure of the electron diffraction tube and connections for the experiment

Fluorescent screen
After leaving the target, the diffracted electrons travel a distance (L) and strike the phosphorous screen. The beam appears as concentric rings around a bright centre. This pattern can be visualized as a set of one-dimensional diffraction pattern of bright spots rotated about the axis of the electron beam.

Precautions:

1. The emission current I_A should NEVER exceed 100 μ A, in order to protect the graphite sample. Keep an eye on the ammeter that monitors the emission current. Adjust the bias voltage V_b to limit the emission current when necessary.
2. Do not leave a bright beam on the fluorescent screen when there is no measurement made. The fluorescent screen has a finite lifetime. Adjust the accelerating voltage V_a to zero when the setup is idle.

Measurement of the powder diffraction pattern of graphite

1. Set up the electrical connections as shown in Fig.4. Use the 6.3Vac output from the kilovolt power supply for the filament voltage V_f and the kilovolt output (0-6 kV) for the accelerating voltage V_a. The bias voltage V_b should be connected to a separate low voltage DC power supply.
2. Before turning on the power supplies, make sure that all the knob settings are at their lowest values. Ask your TA/Technician to check your circuit.
3. Turn on the power supplies. The filament will begin to glow. Wait for one minute before applying the accelerating voltage V_a.
4. Set the bias voltage V_b to about 15V and then slowly increase the accelerating voltage V_a to 5.0 kV. Slowly decrease the bias voltage until the diffraction rings appear sharply. **NOTE:** Always keep the emission current below 100 μ A.
5. Measure the diameter of the two diffraction rings (D_{inner} and D_{outer}) and record the values and the corresponding accelerating voltage V_a in Table 1.
6. Repeat the measurements at the accelerating voltages V_a = 4.5 kV, 4.0 kV, 3.5 kV, 3.0 kV and 2.5 kV.
   NOTE: If the diffraction rings are unclear at V_a = 2.5kV, take another measurement at any value between 5.0kV to 3.0kV.
7. Slowly decrease the accelerating voltage to its lowest value followed by the bias voltage. Turn off all the power supplies and meters.
8. Calculate the square root of the accelerating voltage $\sqrt{V_a}$ and record the results in Table 1.
9. Using Equations (4) and (5) with n = 1 and d_{11} = 0.123 nm, calculate the electron wavelength at each accelerating voltage for the outer diffraction ring. Record your results as the measured wavelengths in Table 2.
10. Calculate the theoretical value of the electron wavelength at each accelerating voltage using Eq. (2). Record your results in Table 2. Compute the percentage difference between the measured and theoretical values of the electron wavelength and record the results in Table 2.

Name	
Date	
Lab session (Day & time)	
Lab partner	

MP6 Electron Diffraction Lab Report

A. Answer the following question BEFORE the lab session (6 pts each)

1. Derive Eq. (2) from Eq. (1).

2. Derive Eq. (6) using Equations (2)-(5).

3. Start with Fig. 1 and explain why the power diffraction pattern consists of a set of concentric rings.

B. Results and data analysis (50 pts)

Table 1 Measurement of the powder diffraction pattern of graphite (35 pts)

accelerating voltage V_a ( )	$\sqrt{V_a}$ ( )	diameter of inner diffraction ring ( )	diameter of outer diffraction ring ( )

Table 2 Measured and calculated electron wavelengths at different values of V_a (15 pts)

accelerating voltage V_a ( )	Measured electron wavelength ( )	Calculated electron wavelength ( )	Percentage difference

C. Data analysis and questions (8 pts each)

4. Use the data in Table 1 and plot $1/D$ as a function of $\sqrt{V_a}$ for the two sets of diffraction rings on the same graph. Fit the data with a linear function and record your fitting results in the lab report. Attach your plot to the lab report.

5. From your fitting results, determine the atomic layer spacing, d_{11} and d_{10}, respectively. Compare your results with the accept values of d_{10} (= 0.213 nm) and d_{11} (= 0.123 nm).

6. From the ratio of the measured values of d_{11} and d_{10}, can you tell what the crystal structure of graphite is like - hexagonal or cubic? Please explain.

7. Compare the measured and calculated values of the electron wavelength in Table 2. Do the resulting percentage differences depend on the accelerating voltage V_a? If so, explain such dependence.

D. Summary of the experiment (20 pts)

Summarize what you have done and your interpretation of the results, especially in respect to how they match the goal of the experiment and what you have learnt from this experiment (2-3 paragraphs, less than 450 words).