Electron Diffraction

Equipment:

Electron diffraction tube (4 units); make sure special red cable is connected
KV power supply & Banana plugs
Ruler

Purpose:

The purpose of this experiment is to demonstrate the wave nature of matter.

Background:

Diffraction through a grating and the subsequent interference pattern is undeniably a property of waves. Therefore, if we observe a diffraction pattern resulting from interference of electron waves, we must conclude that some sort of maniacal channeling is taking place or electrons truly have wave-like properties. If we can use diffraction models to predict known lattice spacings, we can eliminate the possibility of maniacal channeling and strongly conclude that if one attempts to measure an electron's wave properties, an electron behaves as a wave.

In today's experiment we are going to investigate electron waves by looking at their diffraction pattern after passing though a polycrystalline graphite sample supported by a fine mesh grid. The crystal structure for graphite is shown in the figure 1 below. Waves diffract from planes of atoms. As a result, most three-dimensional lattices serve as two-dimensional diffraction gratings. If the grating results from a single crystal, the diffraction pattern will be in the form of a two-dimensional array of "bright spots". If the grating is formed by a polycrystal, i.e. a specimen containing many randomly oriented crystals the diffraction pattern should look like rings. If a cubic material, the diffraction pattern should be a single ring (only more if higher order diffraction fringes are observable).

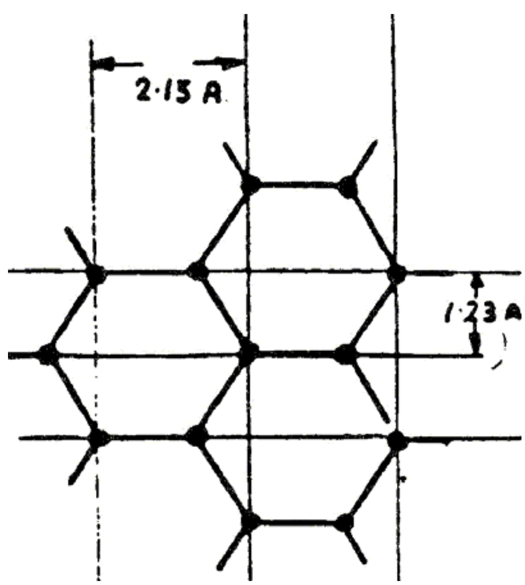


Figure 1: Schematic of the in-plane crystal structure of graphite.

The deBoglie wavelength is known to be related to the particle momentum through the relation

$$\lambda = \frac{h}{p}$$

where h is Planck's constant.

The electron diffraction tube comprises a "gun" which emits a converging narrow beam of cathode rays (electrons) within an evacuated clear glass bulb on the surface of which is deposited a luminescent screen. The cathode rays pass through a thin layer of graphitized carbon supported on a fine mesh grid in the exit aperture of the "gun" and are diffracted into two rings corresponding to separations of the carbon atoms of 1.23 and 2.13 Å. The source of the cathode rays is an indirectly-heated oxide-coated cathode, the heater of which is connected to 4 mm sockets in a plastics cap at the end of the neck; connection to the anode of the "gun" is by a 4 mm plug mounted on the side of the neck.

The tube can be mounted on the Universal stand.

Specifications:

Filament voltage:	Normal 6.3 V a.c./d.c.; max 7.0 V a.c./d.c.
Anode voltage	3,500 - 5,000 V d.c.
Anode current	0.2 - 0.4 mA

The possibility of diffraction:

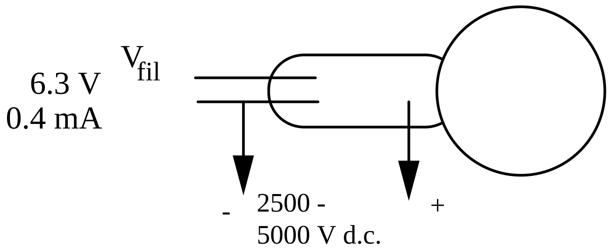
A calculation using de Broglie's equation shows that electrons accelerated through a potential difference of 4 kV have a wavelength of about 0.02 nm or 0.2Å. Interference and diffraction effects, as studied in physical optics, demonstrate the existence of waves. For a simple ruled grating, the condition for diffraction is $\lambda = d \sin \theta$ or for small angles $\theta = \lambda / d$, d being the spacing of the grating. To observe electron diffraction effects, the spacing between atoms must be on the order of or less than the de Broglie wavelength of the electrons used.

It was von Laue who suggested, in connection with x-ray studies, that if fine gratings could not be made by man because of the structure of matter, then perhaps the structure of matter itself could be used as a grating. Bragg, using the cubic system of NaCl, first calculated the interatomic spacings and showed them to be of the right order for x-rays.

A similar calculation using carbon assuming that its atoms form a simple cubic system, can be make, knowing: 12 gms of carbon contain 6 x 10^{23} atoms (N_A); the density of carbon is about 2 gms/cm^3, 1 cm^3 contains 10^{23} atoms so that adjacent carbon atoms will be about $(10^{-23})^{1/3}$ or a little over 2 Å apart. In other words, carbon should provide a grating of the correct spacing for the experiment.

I: Demonstration of Electron Diffraction:

Connect the tube into the circuit shown below. Make sure you ground the negative HV. Switch on the heater supply (6.3 V) and allow about 1 minute for it to stabilize. Adjust the High Volt setting to 4 kV and switch on. (You should immediately have a greenish glow).

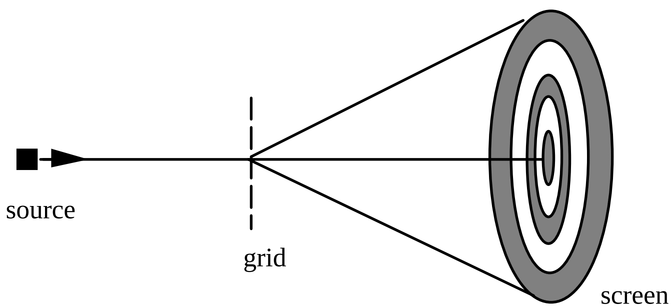


Connection to Tube TEL.2555:

G7: High Voltage +
C5: High Voltage - (ground)

F3: 6.3V AC
F4: 6.3V AC (ground)

A1: not connected



Two prominent rings about a central spot are observed. This demonstration reveals the dual nature of the electron. Use magnet to verify that you have electrons. Variation of the anode voltage causes a change in ring diameter, a decrease in voltage resulting in an increase in diameter. Measure L, the distance between the grating and the rings.

II: Variation of Electron Wavelength with Anode Voltage:

Use the circuit from above and measure (in a darkened room) the diameter of the rings with different anode voltages V_a and tabulate readings (5 or 6 readings).

An expression for the momentum of electrons can be derived from the equation,
$K = eV_a = (1/2)\, m\, v^2$ which substituted in de Broglie's equation gives

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2mK}} = \frac{hc}{\sqrt{2mc^2\, K}}$$

Where hc = 1240 eV nm, mc2 = 0.511 x 10^6 eV, and K is measured in eV.

If the beam travels a distance L after diffraction through a small angle θ, the diameter of the resulting rings is $D = 2\,L\,\theta$

From the diffraction equation, $\lambda = d\,\theta$ for small angles.

Substituting and rearranging the above equations, the ring diameter is found to be inversely proportional to the square root of the anode voltage

$$D = \frac{2\,L}{d}\sqrt{\frac{150}{V_a}}$$

Procedure and Questions:

→ Plot a graph of ring diameter versus $V_a^{-1/2}$

→ How is this change in ring diameter in accord with de Broglie's suggestion that wavelength increases with decrease in momentum. Why?

→ From the fit to your graphs, calculate the spacings, d, for the two diameters (inner, outer). These two numbers imply there are two diffracting planes present in graphiticised carbon.

→ What is the ratio of these spacings? d_{outer}:d_{inner})

→ Verify that the arrangement of carbon atoms is more likely to be hexagonal than cubic. Therefore draw a cubic arrangement and a hexagonal arrangement (see supplied sheet). Measure the different distances between planes, calculate their ratio and compare it with your experiment. See if you can find the diffraction planes by comparing the ratios of d_{outer}:d_{inner}) for the arrangement of the carbon atoms.