Birla Institute of Technology & Science, Pilani

Pilani Campus

PHY F244 : Modern Physics Laboratory

Electron Diffraction

1. **Aim and Objectives** : This experiment aims to study the electron difffraction pattern from the powdered Graphite sample and measure the inter-planar spacing of the Graphite crystal.

2. **Keywords** : de Broglie wavelength, matter waves, Davisson and Germer, Bragg's diffraction, Inter-planar spacing, Electron accelerator.

3. **Theory** :

   In 1924, de Broglie proposed the hypothesis of wave-particle duality, associating with each particle a wave, the de Broglie wave, whose wavelength λ depended on the momentum p of the particle according to

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

   where h is the Planck's constant. Later, the experiments of Davisson and Germer established the fact that electrons are scattered off a crystal of nickel and produce a diffraction pattern, which was the first experimental verification of the de Broglie hypothesis.

   Knowledge of the scattered electron's kinetic energy can calculate the electron's momentum. If, say, the electrons are accelerated by the potential difference of U_A Volts. The kinetic energy of the electron would be given by,

$$\frac{p^2}{2m_e} = |e|U_A \implies p = \sqrt{2m_e|e|U_A} \tag{2}$$

   where, m_e and $|e|$ are the mass and the charge of the electron and U_A is the anode voltage. As a result, the de Broglie wavelength of the electron will be given as,

$$\lambda = \frac{h}{\sqrt{2m_e|e|U_A}} \tag{3}$$

   The electrons are emitted by the thermionic emission by the cathode and accelerated to KeV or energies using appropriate potentials. The energetic electron beam then strikes a thin film of the powered polycrystalline Graphite (different planes of periodic arrangements of atoms are present). The diffraction of the electron (or x-ray) from the periodic crystal is routinely used to study the crystal structure of the

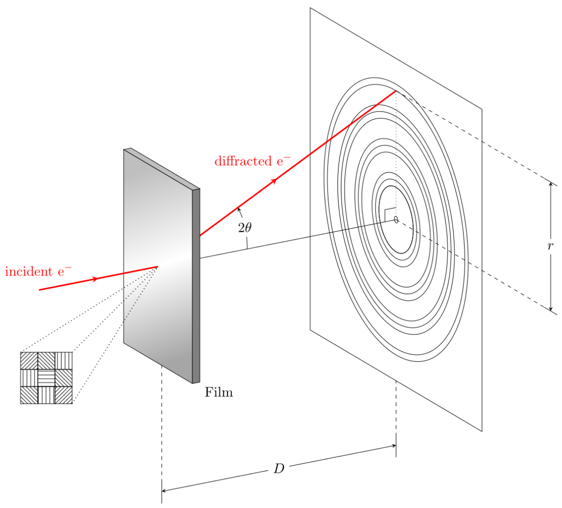

Figure 1: Electron diffraction pattern.

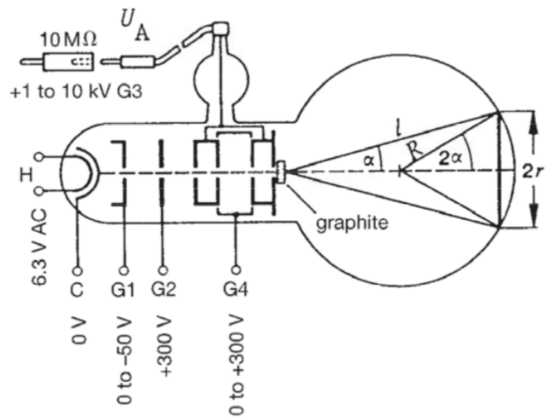

Figure 2: Schmatic of the experimental setup.

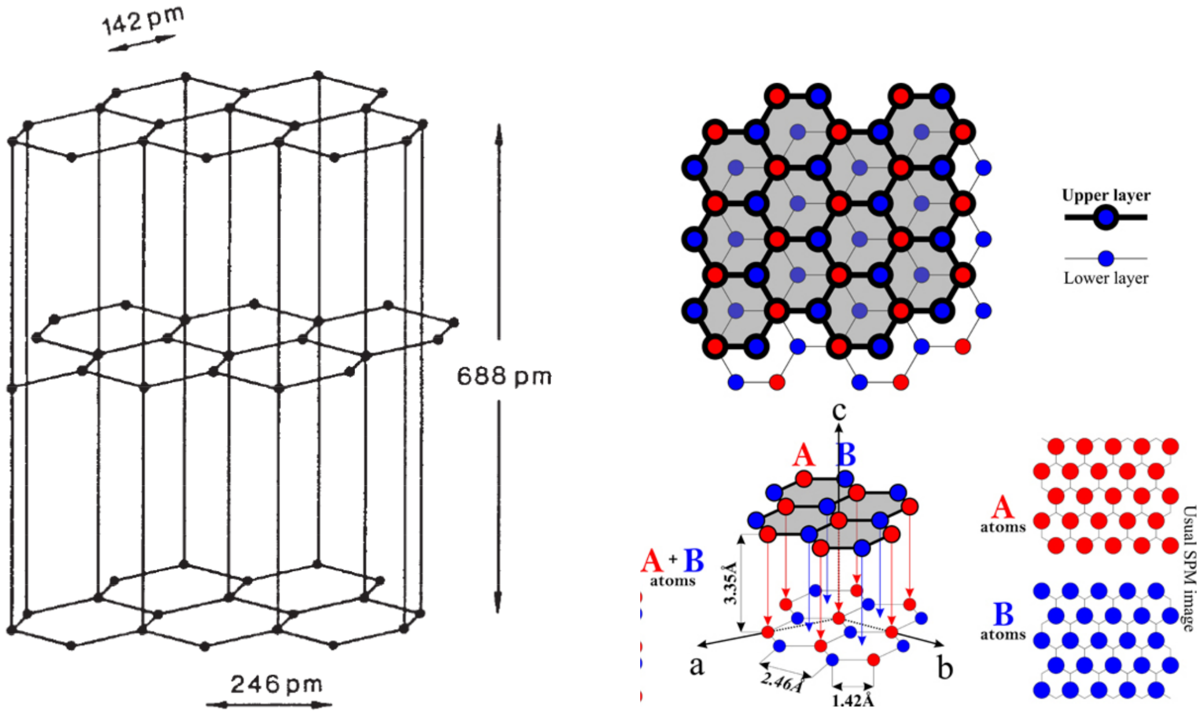

Figure 3: Crystal lattice of graphite. Two different lattice constants, $d_1 = 142$ pm and $d_2 = 246$ pm, are visualized. [image courtsey: Click Here]

target materials. Bragg's diffraction law relates the lattice spacing (d) with the diffraction angle θ and the wavelength of the incident electron or x-rays, and is given as

$$2d\sin\theta = n\lambda \quad ; \quad n = 1,2,3... \tag{4}$$

here, n is the order of the diffraction. The advantage of the powdered sample is that the crystals are oriented randomly, which allows us to sample all possible angles of incidence without changing the direction of the electron beam. If electrons act like a wave, different atomic planes will produce constructive interference, and the resulting electron diffraction pattern will consist of concentric rings. In such a random aggregate of crystals (i.e., a powder), there are always crystals with the same set of lattice planes in an orientation that satisfies Bragg's Law. All these crystals will diffract the incident beam strongly over the same angle 2θ, while other directions will result in destructive interference, as shown in Figure 1. The result is a diffracted beam in the shape of a cone with a top angle 4θ.

The schematic diagram of the experimental setup is shown in Figure 2. There is a fluorescent screen on the Glass bulb of Radius $R = 65$ mm. Most of the non-diffracted electrons will hit the screen, forming a bright green spot. Few electrons that undergo the diffraction will form a ring of Radius r, say. The angle $\alpha = 2\theta$ is the opening angle of the respective cone, as can be inferred from both Figures 1 and 2. From the geometrical aspect, it can be observed from the Figure 2,

$$\sin(2\alpha) = \frac{r}{R} \tag{5}$$

where r is the Radius of the ring observed, and $R = 65$ mm is the Radius of the Glass bulb. The angle α can be written in terms of Bragg's diffraction angle and simplifies to

$$\sin(4\theta) = \frac{r}{R} \implies \theta = \frac{1}{4}\sin^{-1}\left(\frac{r}{R}\right). \tag{6}$$

Each crystalline plane would diffract the electron, forming rings of different Radius on the screen. In this setup, we will only observe the first order diffraction, i.e. $n = 1$ in Eq. 4, and hence, only two central ring diameters (Radius) need to be recorded. From Eq. 4 and Eq. 6 we can obtain the lattice spacing d corresponding to a particular crystalline plane for $n = 1$ as:

$$d = \frac{n\lambda}{2\sin\theta} = \frac{n\lambda}{2\sin\left(0.25\sin^{-1}(r/R)\right)} \tag{7}$$

Under the small angle approximation Eq. 7 can be simplified as with $n = 1$:

$$d \approx \frac{2R\lambda}{r} \implies \boxed{r \approx \frac{2R}{d}\lambda} \tag{8}$$

4. **Experimental Procedure** :
   (a) Make the anode voltage knob to zero and turn on the setup.
   (b) Vary the anode voltage and measure the diameter of the two inner rings.
   (c) These two inner rings correspond to the first-order electron diffraction from two different lattice planes.
   (d) Plot the graph between the de Broglie wavelength associated with the anode voltage U_A (kV) and the Radius of the two inner rings separately.
   (e) As can be seen, the slope of the graph can be calculated, and accordingly, the lattice spacing d can be estimated.

5. **Tasks** :
   (a) Create an appropriate observation table which records the U_A (kV), calculate λ in picometers.
   (b) Measure the diameter of two inner rings as a function of the U_A (kV). You can measure the diameter along two directions i.e., horizontal and vertical, and take the average of the same to reduce the error.
   (c) Plot the graph of the Radius of the rings in mm and the λ in picometers (10^{-12} m).
   (d) Calculate the slope and estimate the lattice spacing d_1 and d_2.
   (e) The theoritical values for d_1 and d_2 are already shown in the Figure 3. Estimate the percentage error.
   (f) Also calculate the lattice spacing when the small angle approximations are not incorporated, i.e., using Eq. 7.

6. **Observations and Results** :

S.N.	U_A (kV)	λ (pm)	D_1 (mm)	D_2 (mm)	r_1 (mm)	r_2 (mm)
1						
2						
3						
4						
5						
6						
7						

The instruction manual for the experimental setup is also appended.

Related Topics

Bragg reflection, Debye-Scherrer method, lattice planes, graphite structure, material waves, de Broglie equation.

Principle

This famous experiment demonstrates the wave-particle duality of matter using the example of electrons. The diffraction pattern of fast electrons passing a polycrystalline layer of graphite is visualized on a fluorescent screen. The interplanar spacing in graphite is determined from the diameter of the rings and the accelerating voltage. For the investigations on this phenomenon Louis de Broglie won the Nobel Prize in 1929 and George Thomson and Clinton Davisson in 1937.

Equipment

1	Electron diffraction tube a. mounting	06721-00
1	High voltage supply unit, 0-10 kV	13670-93
1	Connecting cord, 30 kV, 500 mm	07366-00
1	Power supply, 0...600 VDC	13672-93
1	Vernier caliper, plastic	03014-00
1	Connecting cord, safety,32A, 50cm, green-yellow	07336-15
2	Connecting cord, safety,32A, 25cm, green-yellow	07335-15
2	Connecting cord, safety,32A, 10 cm, yellow	07334-02
2	Connecting cord, safety,32A, 50cm, red	07336-01
1	Connecting cord, safety,32A, 50cm, yellow	07336-02
1	Connecting cord, safety,32A, 50cm, blue	07336-04
2	Connecting cord, safety,32A, 50cm, black	07336-05
1	High-value resistor, 10 MOhm	07160-00
1	Socket adapter for safety tubing, 10 pcs.	07207-00

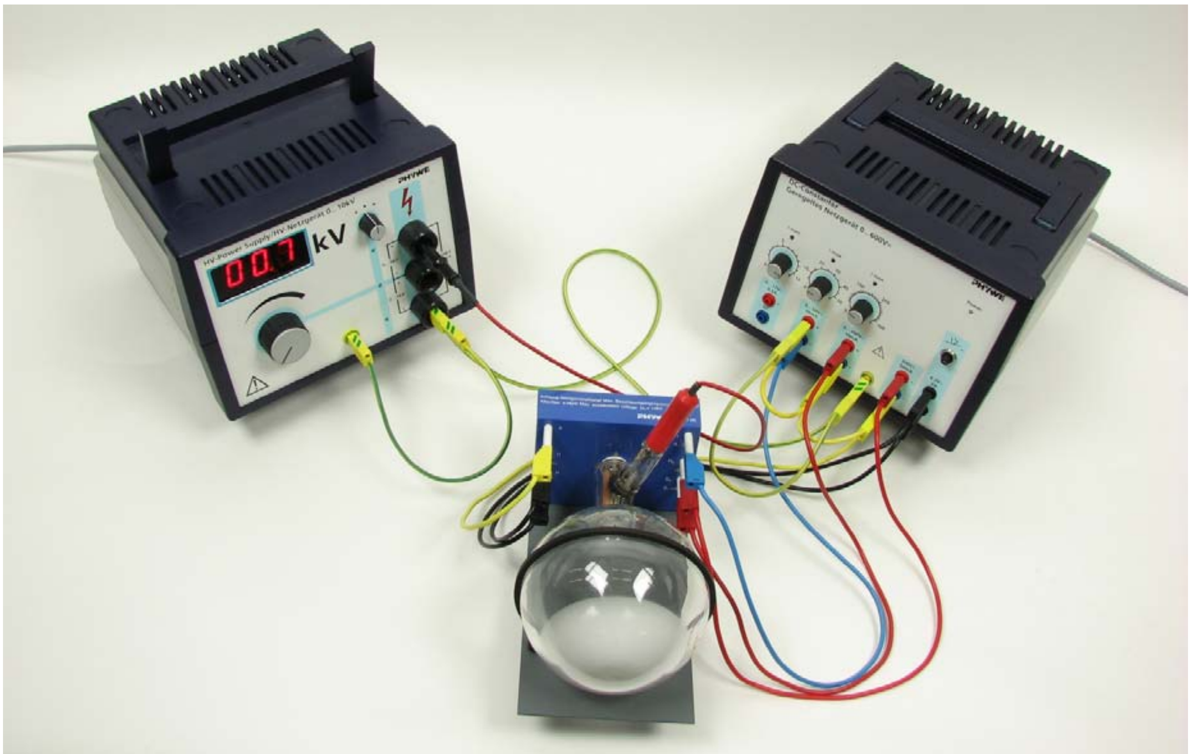

Fig. 1: Set-up of experiment P2511300

Tasks

1. Measure the diameter of the two smallest diffraction rings at different anode voltages.
2. Calculate the wavelength of the electrons from the anode voltages.
3. Determine the interplanar spacing of graphite from the relationship between the radius of the diffraction rings and the wavelength.

Set-up and Procedure

Set up the experiment as shown in Fig. 1. Connect the sockets of the electron diffraction tube to the power supply as shown in Figs. 1 and 2.

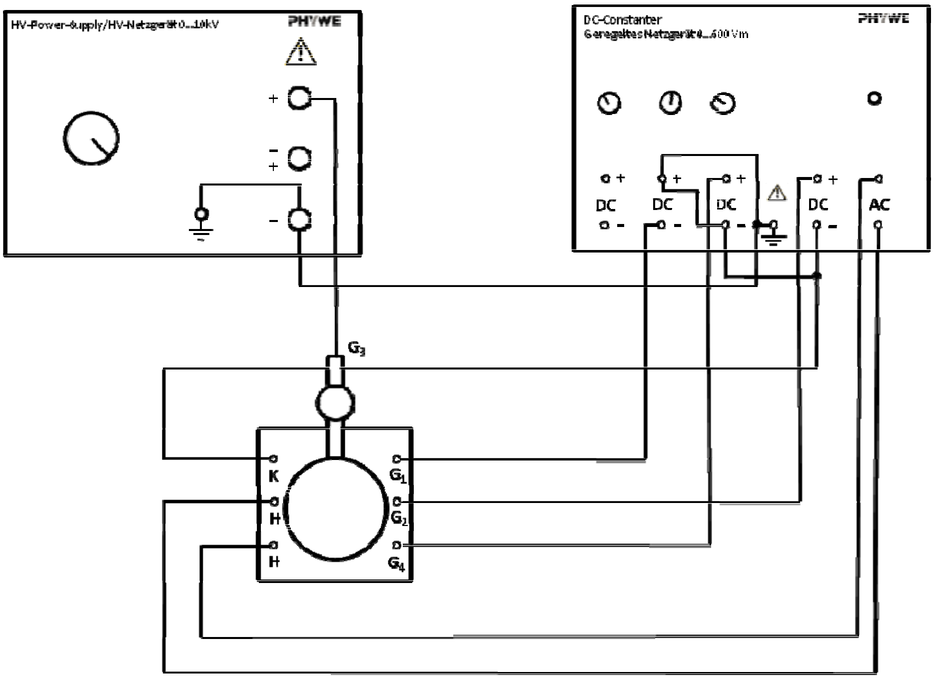

Fig. 2: Electrical connections for the experiment.

Set the Wehnelt voltage G1 and the voltages at grid 4 (G4) and G3 so that sharp, well defined diffraction rings appear. Read the anode voltage at the display of the HV power supply. (Please note that the voltage on the anode approximately corresponds to the voltage shown on the display of the power supply only if the tube current is small << 1mA. Otherwise the voltage drop on the 10 MΩ resistors cannot be neglected. Make sure that the Wehnelt voltage is set to -50 V. Smaller absolute values of Wehnelt voltages lead to significant tube current increase and thus strong voltage drop on the resistor.) To determine the diameter of the diffraction rings, measure the inner and outer edge of the rings with the vernier caliper (in a darkened room) and take an average. Note that there is another faint ring immediately behind the second ring.

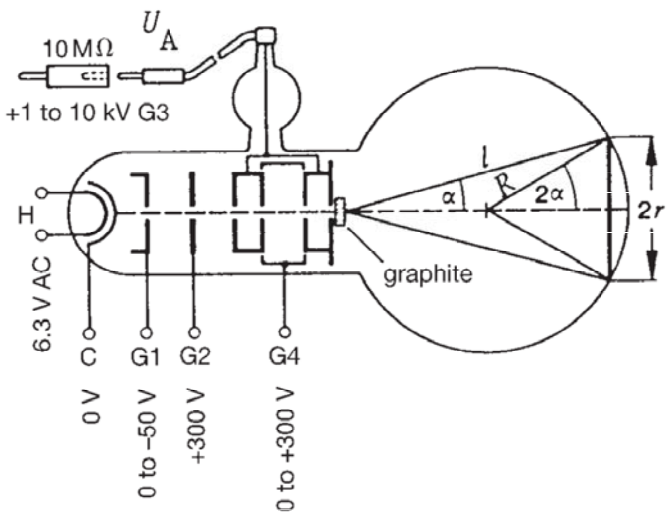

Fig. 3: Set-up and power supply to the electron diffraction tube.

