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

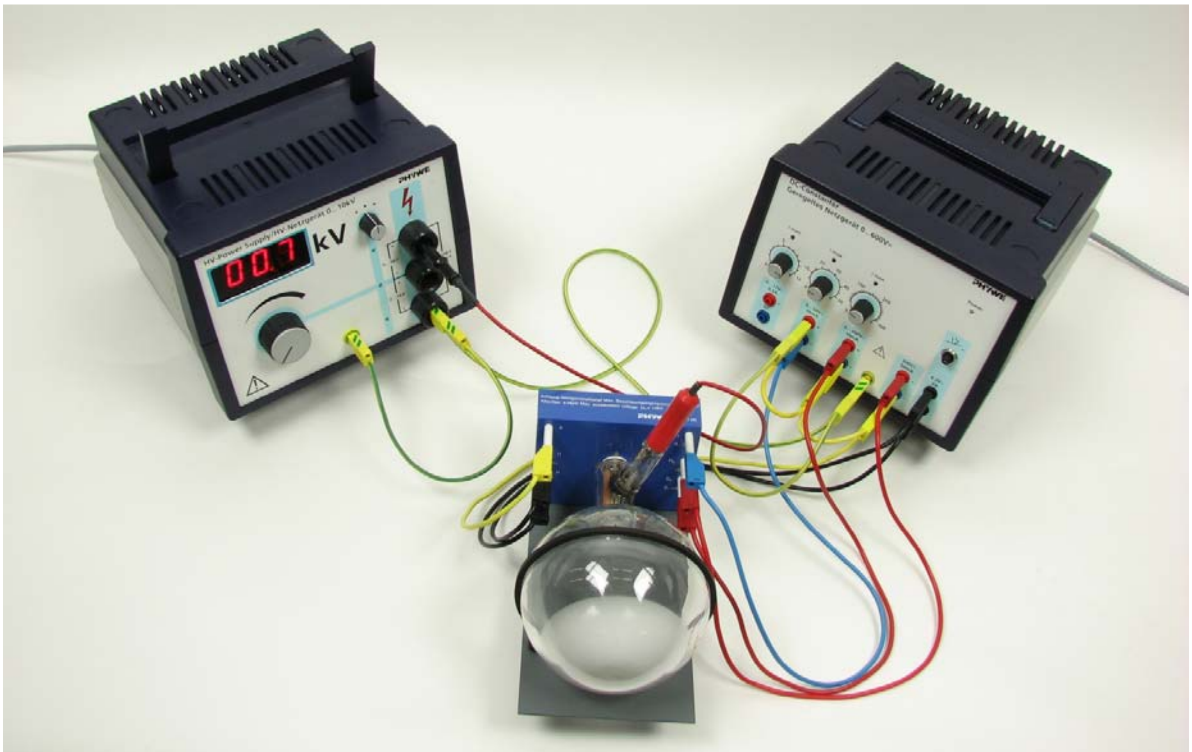

Fig. 1: Set-up of experiment P2511300

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.

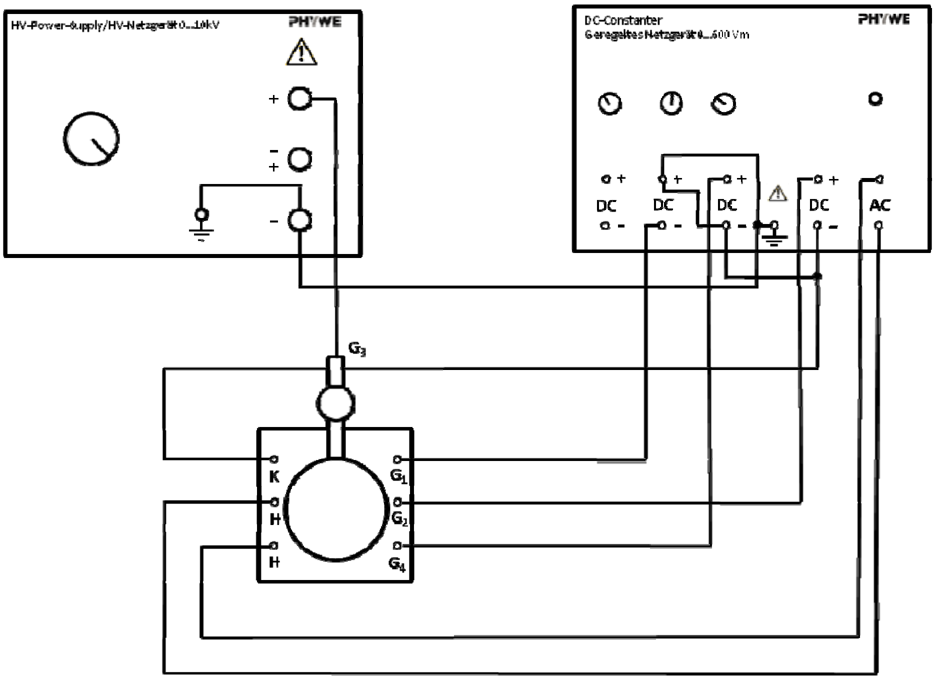

Fig. 2: Electrical connections for the experiment.

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.

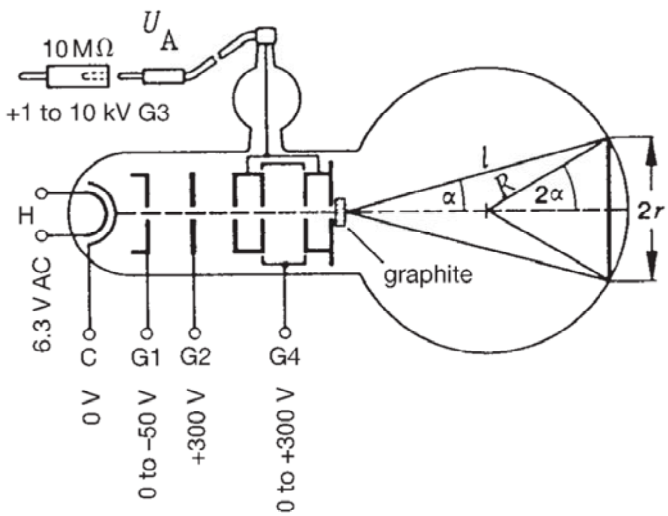

Fig. 3: Set-up and power supply to the electron diffraction tube.

Theory and evaluation

In 1926, De Broglie predicted in his famous hypothesis that particles should also behave like waves. This hypothesis was confirmed concerning electrons three years later independently by George Thomson and Clinton Davisson, who observed diffraction patterns of a beam of electrons passing a metal film and a crystalline grid, respectively. All of them won the Nobel prize for their investigations, De Broglie in 1929 and Thomson and Davisson in 1937.

Electron diffraction is used to investigate the crystal structure of solids similar to X-Ray diffraction. Crystals contain periodic structural elements serving as a diffraction grating that scatters the electrons in a predictable way. Thus, the diffraction pattern of an electron beam passing through a layer of a crystalline material contains information about the respective crystal structure. In contrast to X-Rays, electrons are charged particles and therefore interact with matter through coulomb forces providing other information about the structure than X-ray diffraction.

To explain the interference phenomenon of this experiment, a wavelength λ, which depends on momentum, is assigned to the electrons in accordance with the de Broglie equation:

$$\lambda = \frac{h}{p} \qquad (1)$$

where h = 6.625 · 10^{-34} Js, Planck's constant.

The momentum can be calculated from the velocity v that the electrons acquire under acceleration voltage U_A:

$$\frac{1}{2}mv^2 = \frac{p^2}{2m} = e \cdot U_A$$

The wavelength is thus

$$\lambda = \frac{h}{\sqrt{2\mathrm{m}_{\mathrm{e \cdot U_A}}}} \qquad (3)$$

where e = 1.602 · 10^{-19} As (the electron charge) and m = 9.109 · 10^{-31} kg (rest mass of electron).

At the voltages U_A used, the relativistic mass can be replaced by the rest mass with an error of only 0.5%. The electron beam strikes a polycrystalline graphite film deposite on a copper grating and is reflected in accordance with the Bragg condition:

$$2d \sin\theta = n \cdot \lambda, n = 1,2,3 \ldots \qquad (4)$$

where d is the spacing between the planes of the carbon atoms and θ is the Bragg angle (angle between electron beam and lattice planes).

In polycrystalline graphite the bond between the individual layers (Fig. 4) is broken so that their orien-

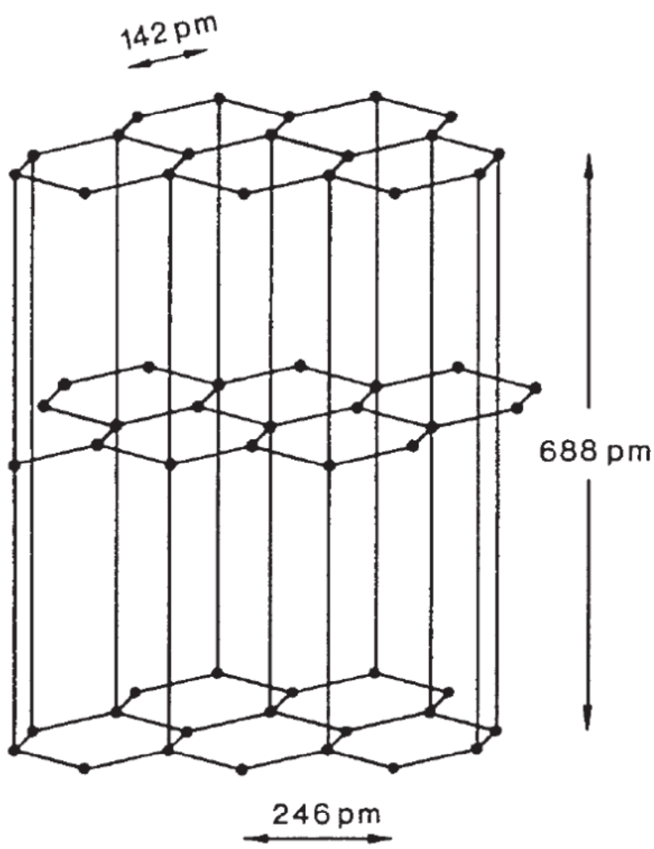

Fig. 4: Crystal lattice of graphite.

tation is random. The electron beam is therefore spread out in the form of a cone and produces interference rings on the fluorescent screen. The Bragg angle θ can be calculated from the radius of the interference ring but it should be remembered that the angle of deviation α (Fig. 3) is twice as great:

$$\alpha = 2\theta.$$

From Fig. 3 we read off

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

where R = 65 mm, radius of the glass bulb.

Now, $\sin 2\alpha = 2\sin\alpha\cos\alpha$

For small angles α (cos 10° = 0.985) can put

$$\sin 2\alpha \cong 2\sin\alpha \qquad (6)$$

so that for small angles θ we obtain

$$\sin 2\alpha = \sin 4\theta \cong 4\sin\theta \quad (6a)$$

With this approximation we obtain

$$r = \frac{2R}{d} \cdot n \cdot \lambda \qquad (7)$$

The two inner interference rings occur through reflection from the lattice planes of spacing d_1 and d_2 (Fig. 5), for n = 1 in (7).

The wavelength is calculated from the anode voltage in accordance with (3):

$\frac{U_A}{kV}$	$\frac{\lambda}{pm}$
4.00	19.4
4.50	18.3
5.00	17.3
5.50	16.5
6.50	15.2

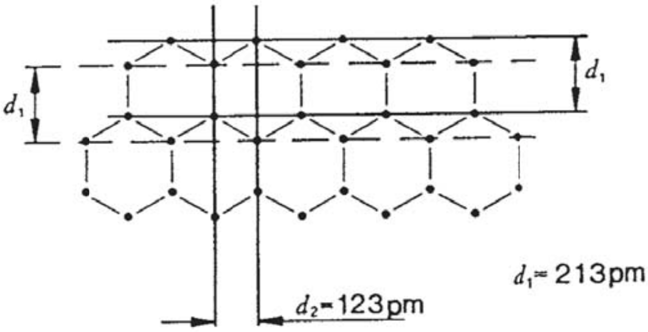

Fig. 5 : Graphite planes for the first two interference rings.

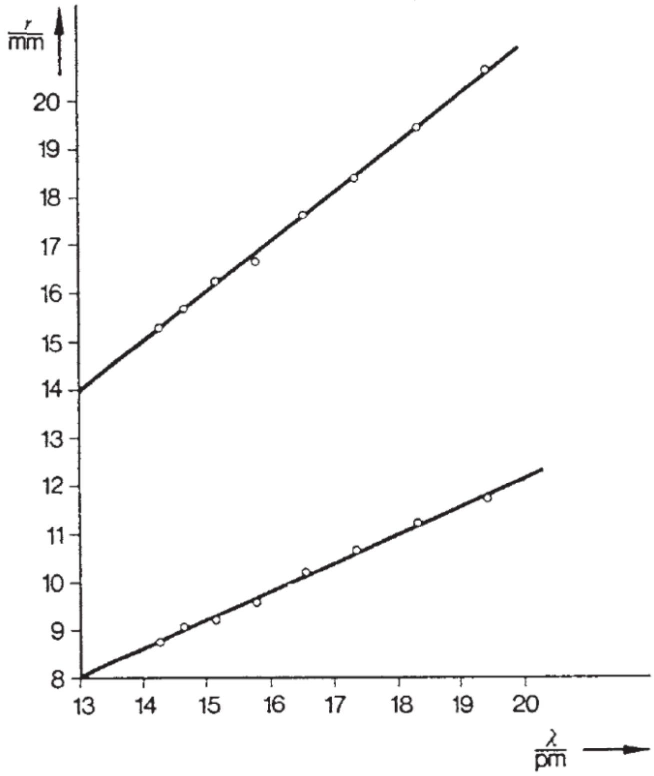

Fig. 6: Radii of the first two interference rings as a function of the wavelength of the electrons.

7.00	14.7
7.40	14.3

Applying the regression lines expressed by

Y = AX + B

to the measured values from Fig. 6 gives a slopes

$A_1 = 0.62\ (2) \cdot 10^9$
$A_2 = 1.03\ (2) \cdot 10^9$

and the lattice constants

d_1 = 211 pm
d_2 = 126 pm

in accordance with (7),

$$\frac{T_i}{\lambda} = A_i = \frac{2R}{d_i} \quad \text{and}$$

$$d_i = \frac{2R}{A_i}$$

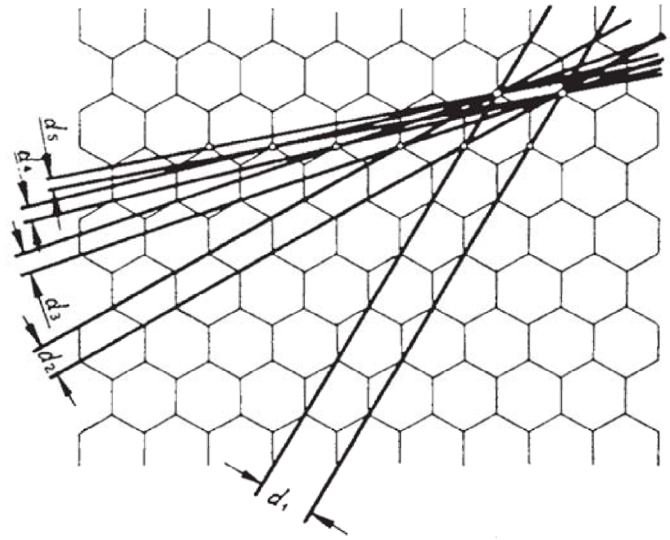

Fig. 7: Interplanar spacing in graphite
d_1 = 213 pm; d_2 = 123 pm; d_3 = 80.5 pm;
d_4 = 59.1 pm; d_5 = 46.5 pm.

Notes

- The intensity of higher order interference rings is much lower than that of first order rings. Thus, for example, the second order ring of d_1 is difficult to identify and the expected fourth order ring of d_1 simply cannot be seen. The third order ring of d_1 is easy to see because graphite always has two lattice planes together, spaced apart by a distance of d1/3. (Fig. 7) In the sixth ring, the first order of ring of d_4 clearly coincides with the second order one of d_2.

  Radii (mm) calculated according to (4) for the interference rings to be expected when U_A = 7 kV:

	n = 1	n = 2	n =3	n = 4
d_1	8.9	17.7	26.1	34.1
d_2	15.4	29.9		
d_3	23.2			
d_4	31.0			
d_5	38.5			

- The visibility of high order rings depends on the light intensity in the laboratory and the contrast of the ring system which can be influenced by the voltages applied to G1 and G4.

- The bright spot just in the center of the screen can damage the fluorescent layer of the tube. To avoid this reduce the light intensity after each reading as soon as possible.

