EXPERIMENT 3: ELECTRON DIFFRACTION

Related Topics

Bragg reflection, 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.

Tasks

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

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:

$$\lambda = \frac{\mathrm{h}}{P}$$

where $h = 6.625 \cdot 10^{-34}$ 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

$$\lambda = \frac{\mathrm{h}}{\sqrt{2m \cdot e \cdot U_A}}$$

where e = 1.602 x 10^{-19} A.s (the electron charge) and m = 9.109 x 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 Bragg condition:

$$2d\sin\theta = n\lambda, \qquad \mathrm{n} = 1,2,3 \ldots$$

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 orientation 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:

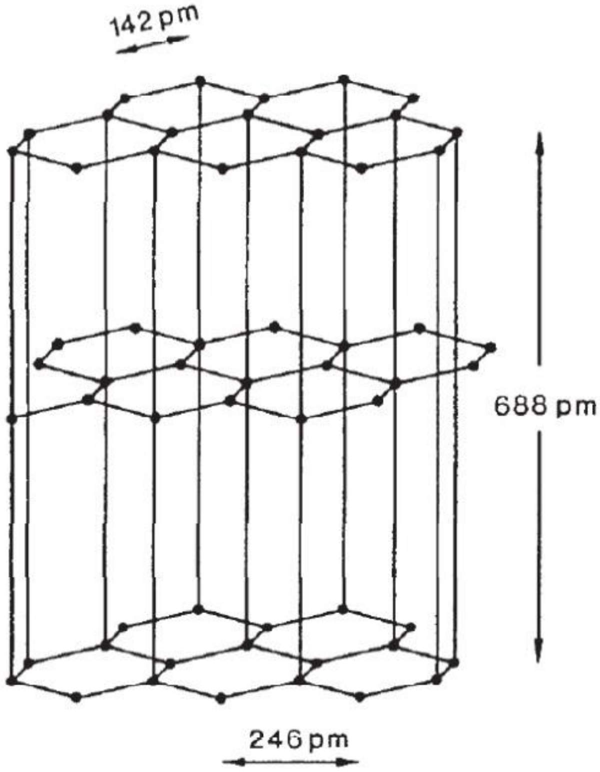

Fig. 4: Crystal lattice of graphite.

$$\propto = 2\theta$$

From Fig. 3 we read off

$$\sin 2 \propto = \frac{r}{R}$$

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

Now, sin 2α=2 sinα cosα

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

$$\sin 2\alpha \approx 2 \sin\alpha$$

so that for small angles θ we obtain

$$\sin 2\alpha = \sin 4\theta \approx 4 \sin\theta$$

With this approximation we obtain

$$r = \frac{2R}{d}\, n\, \lambda$$

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

The wavelength can be calculated from the anode voltage.

U_A (kV)	λ (pm)	r_1 (mm)	r_2 (mm)	d_1 (pm)	d_2 (pm)
4.00					
4.50					
5.00					
5.50					
6.00					
6.50					
7.00					

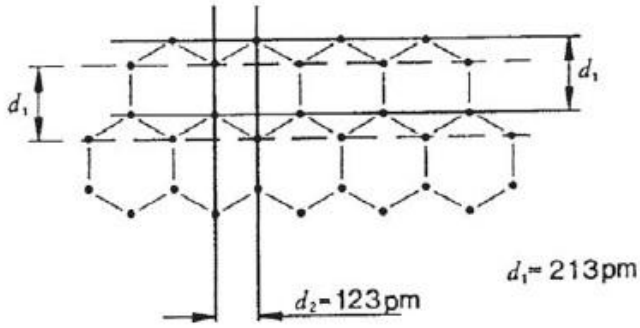

Fig. 5 : Graphite planes for the first two interference rings.

Equipment

Electron diffraction tube, Vernier caliper, Power suppliers, Digital Multimeters

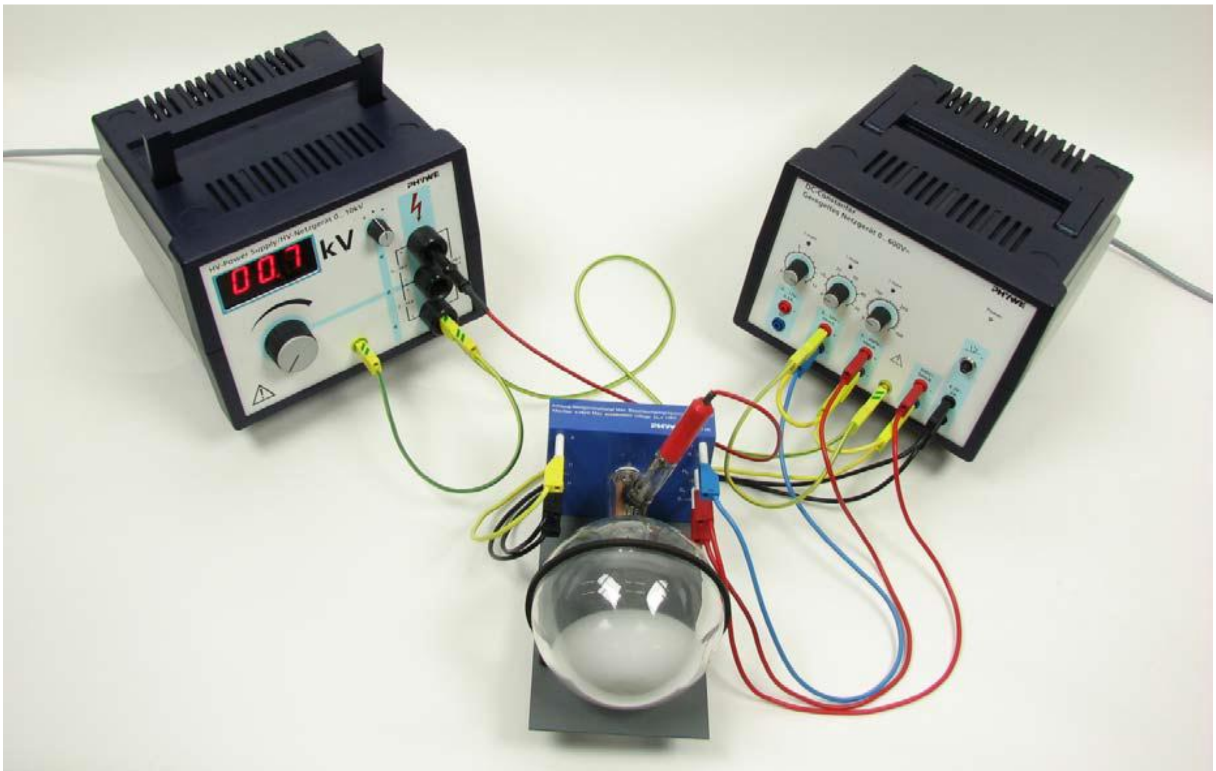

Fig.1: Experimental set-up for electron diffraction.

Set-up and Procedure

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 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.

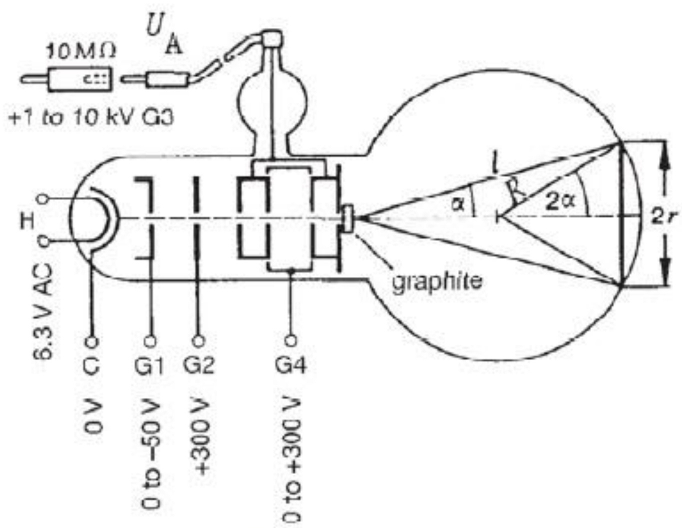

Fig. 3: Set-up and power supply to the electron diffraction tube.