Electron diffraction

Physics | Modern Physics | Quantum physics

Difficulty level	Group size	Preparation time	Execution time
-	-	-	-

This content can also be found online at:

http://localhost:1337/c/5f0ecd19b6127b000304484a

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General information

Application

Scanning electron microscope

Electron diffraction is most frequently used in solid state physics and chemistry to study the crystal structures of solids through a diffraction pattern.

In scanning electron microscope (SEM), the electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample.

Other applications are transmission electron microscope (TEM) and electron backscatter diffraction.

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Other information (1/2)

Prior knowledge

In quantum mechanics, wave-particle duality explains that every particle may be described as either a particle or a wave. Since the electron beam has a wave-like character, it is diffracted as it passes through a crystal.

Scientific 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.

Other information (2/2)

Learning objective

Understanding the major interactions of electrons diffraction through a crystal lattice and wave-particle duality.

Tasks

1. Measure the diameter of the 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

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Safety instructions

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For this experiment the general instructions for safe experimentation in science lessons apply.

Hot cathode tubes are thin-walled, highly evacuated glass tubes. Treat them carefully as there is a risk of implosion! Do not subject the tube to mechanical stresses.

When the tube is in operation, the stock of the tube may get hot. If necessary, allow the tube to cool before dismantling. Please do not handle the beam tube during the experiment.

Theory (1/9)

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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.

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Theory (2/9)

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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 $h = 6.625 \cdot 10^{-34}\ Js$, Planck's constant.

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

$$E_{kin} = \frac{1}{2}mv^2 = \frac{p^2}{2m} = e \cdot U_A \qquad (2)$$

Theory (3/9)

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The wavelength is thus

$$\lambda = \frac{h}{\sqrt{2meU_A}} \qquad (3)$$

where $m = 9.109 \cdot 10^{-31}\ kg$ (rest mass of electron) and $e = 1.602 \cdot 10^{-19}\ As$ (elementary electric charge).

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:

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

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).

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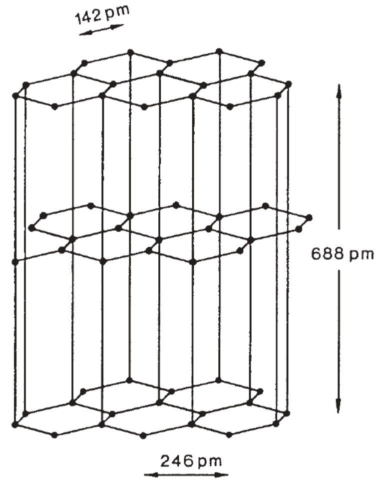
Theory (4/9)

In polycrystalline graphite the bond between the individual layers 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.



Crystal lattice of graphite

Theory (5/9)

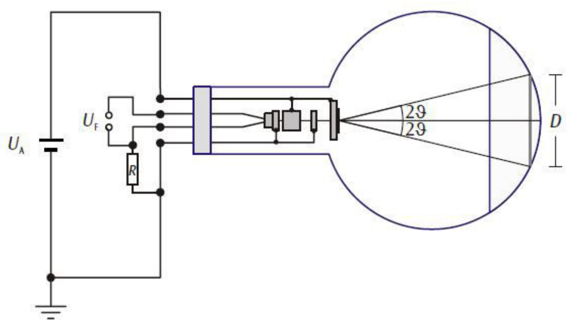
The Bragg angle θ can be calculated from the radius of the interference ring but it should be remembered that the angle of deviation α is twice as great:

$$\alpha = 2\theta$$

From figure, it's read off

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

where $R = 50mm$, is the radius of the glass bulb and r, is the radius of the interference rings.



Schematic diagram of the electron diffraction tube

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Theory (6/9)

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

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

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

so that for small angles θ we obtain

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

With this approximation we obtain

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

Theory (7/9)

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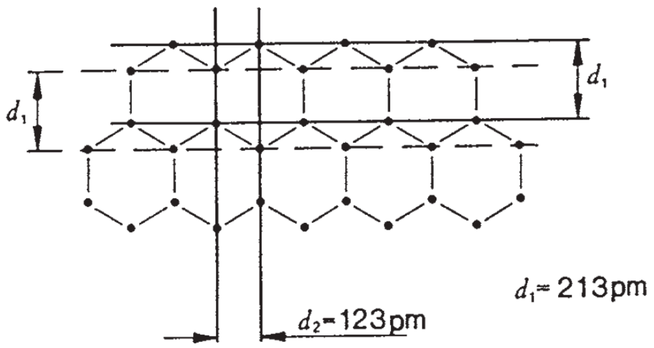
The two inner interference rings occur through reflection from the lattice planes of spacing d_1 and d_2 , for n = 1 in (7).



Graphite planes for the first two interference rings

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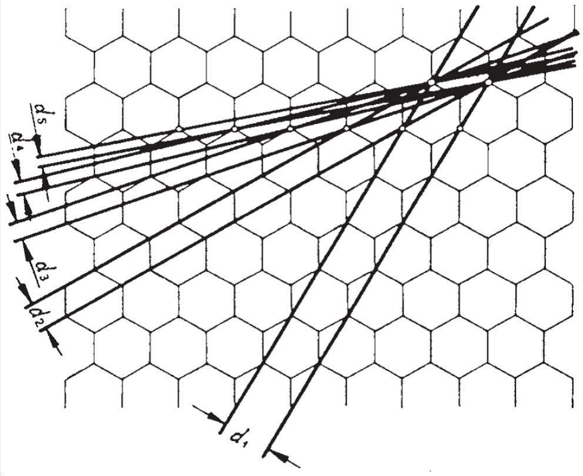
Theory (8/9)

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 1/3*d*.

In the sixth ring, the first order of ring of d_4 clearly coincides with the second order one of d_2.



Interplanar spacing in graphite

Theory (9/9)

Notes

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 electron diffraction tube.

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.

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Equipment

Position	Material	Item No.	Quantity
1	Electron diffraction tube	06721-02	1
2	Holder for electron diffraction tube	06721-03	1
3	Operating unit for electron diffraction tube 230 V	06721-04	1
4	Safety experiment cable for electron diffraction tube	06721-05	1

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Setup and procedure

Setup (1/2)

Push the electron diffraction tube into the tube holder, ensuring that the contact pins of the tube engage with the correct holes of the holder. The middle pin of the tube should project slightly at the back of the holder.

Connect sockets F3 and F4 of the tube holder to the heater voltage output terminals of the 5 kV high-voltage power supply.

Electron diffraction tube

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Setup (2/2)

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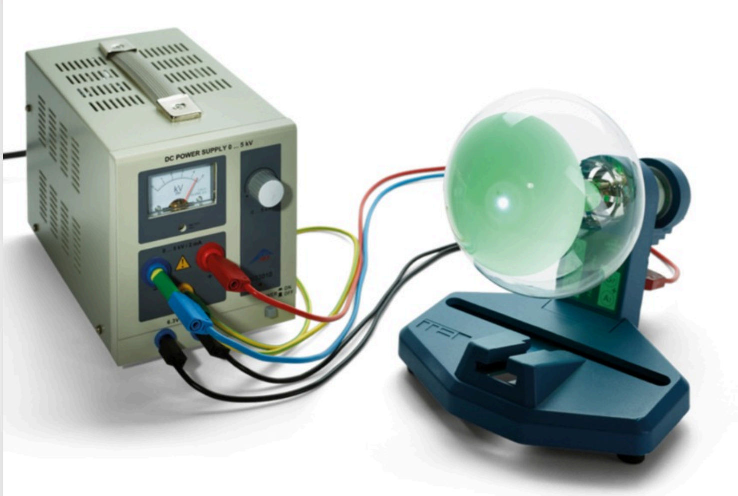

Experimental setup

Connect the negative output terminal of the 5 kV high-voltage power supply to socket C5 of the tube holder and the positive output terminal to socket G7, and connect the safety earth terminals.

Procedure

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Apply the high voltage at 5000 V and measure the diameters of the two diffraction rings on the curved fluorescent screen.

Measure the inner and outer edge of the rings with the vernier caliper (in a darkened room) and take an average

Reduce the voltage in steps of 500 V and measure the diffraction rings in each case.

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Evaluation (1/4)

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U_A/kV	λ/pm
5000	17.4
4500	18.3
4000	19.4
3500	20.8
3000	22.4
2500	24.6

Calculated electron wavelengths at different accelerator voltages

Distance to the fluorescent screen *L*, radius *R* of the glass sphere of the electron diffraction tube and lattice constants *d* are:

$L = 130\,mm$

$R = 50\,mm$

$d_1 = 123\,pm$

$d_2 = 213\,pm$

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

Evaluation (2/4)

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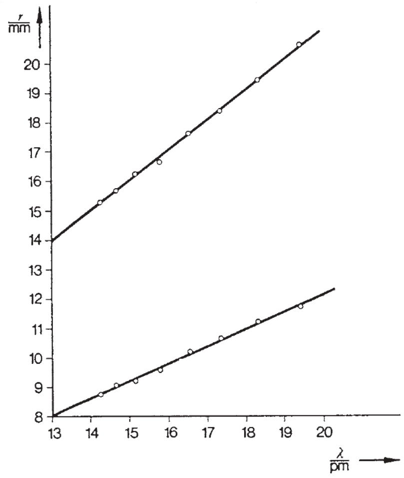

Radii of the first two interference rings as a function of the wavelength of the electrons

By applying the regression lines expressed by Y = AX + B to the measured values from the figure, it gives a slopes

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

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

and the lattice constants

$d_1 = 211\,pm$ and

$d_2 = 126\,pm$

in accordance with (7).

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Evaluation (3/4)

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What happens as the accelerating voltage is increased?

If the accelerating voltage is increased, the electrons have greater ________ and hence shorter ________. Therefore, the waves are diffracted ________ and so the diameters of the diffraction rings ________.

- wavelength
- energy
- decrease
- less

Check

Evaluation (4/4)

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Which of these occurs in the electron diffraction through a crystal?

- [ ] Nuclear interactions
- [ ] Constructive interference
- [ ] Electron Scattering

Check

The obtained results of electrons diffraction are dependant on:

- [ ] Number of atomic layers
- [ ] Composition of the crystal
- [ ] Spacing between atomic layers

Check

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Slide	Score / Total
Slide 22: Accelerating voltage	0/4
Slide 23: Multiple tasks	0/4

Total Score 0/8

Show solutions

Retry

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