EXPERIMENT 21

ELECTRON DIFFRACTION

PURPOSE

- To examine de Broglie postulate on the material waves.
- To determine the inter- planar spacing in graphite from the electron diffraction images.

APPARATUS

Electron diffraction vacuum tube with polycrystalline graphite lattice. High voltage power supply with digital voltmeter. Universal power supplies, plastic vernier caliper.

DESCRIPTION OF THE EXPERIMENT

Fast electrons are diffracted from a polycrystalline layer of graphite a result the bright interference rings appear on the fluorescent screen. The interplanar spacing of the structure can be determine from the diameter of the rings and accelerating voltage.

In the present experiment observations are to be made using the electron diffraction vacuum tube with graphite lattice placed inside it (Fig.1.). The high speed electrons are produced by the electron gun (H,G1 - Fig.1.) and by means of electronic lens system (G1, G2, G4, - Fig.1.)they are brought into the narrow beam.
The electrons beam strikes the polycrystalline graphite film deposited on a copper grating (see Fig.1.) and is reflected.

In accordance with the de Broglie postulate, electron beam behaviour can be described in terms of wave phenomena.
The material wave wavelength - λ- which depends on momentum - p - is assigned to the electrons - Eq.1.:

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

where:

$h = 6.625 \cdot 10^{-34}$ [Js] - the Planck's constant

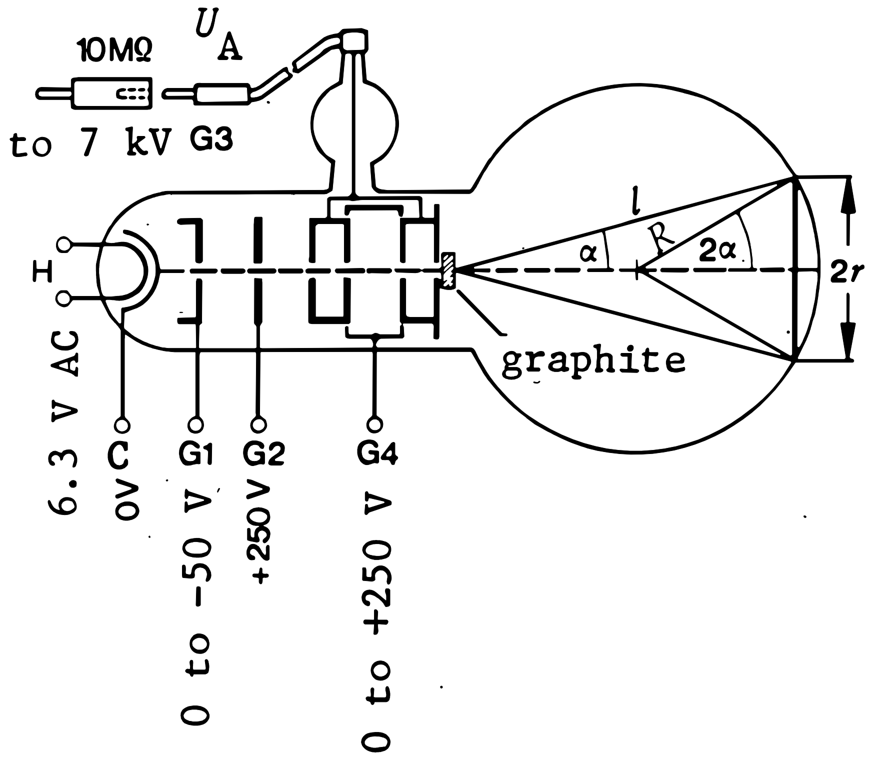

Fig.1. Electron diffraction vacuum tube

The momentum - *p* - can be calculated from the velocity - *v* - that electron acquire under the acceleration voltage - U_A - Eq. 2.:

$$\frac{1}{2}mv^2 = \frac{p^2}{2m} = eU_A \qquad (2)$$

where:

e = $1.602 \cdot 10^{-19}$ [C] - the electron charge
m = $9.109 \cdot 10^{-31}$ [kg] - rest mass of electron (in fact it should be replaced by the relativistic mass, the estimated error of such approximation is about 0.5%)

Thus the wavelength of electron material wave is given by Eq.3.:

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

The reflection of the electron beam on the structural lattice of crystal can be described by the Bragg condition -Eq. 4.:

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

where :

d - the spacing between the planes of the carbon atoms
θ - Bragg angle (angle between incident beam and lattice planes)

In the used polycrystalline graphite the ideal structure (Fig.2) is broken, so orientation of the individual layers is random. Therefore the diffracted beam has the form of a cone and when it strikes the fluorescent screen of the vacuum tube it produces the interference rings.
The two inner interference rings occur through the reflection from the lattice planes of spacing: d_1 , d_2 (see Fig.3).
Bragg angle θ - can be calculated from the radius of the interference ring but it should be remembered that the angle of deviation - α - (see Fig.1.) is given by - Eq.5.:

$$\alpha = 2\theta \qquad (5)$$

From Fig.1. one can find that - Eq.6.:

$$\sin 2\alpha = \frac{r}{R} \qquad (6)$$

where: r - the radius of the interference ring
R - the radius of the glass bulb, $R = 65 \cdot 10^{-3}$ [m]

For small angles - θ - ($\sin\alpha = \sin 2\theta \approx 2 \sin \theta$) one can obtain - Eq.7.:

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

The intensity of higher orders interference rings is much lower than that of the first order and the disturbing effect of coincidence occurs. So, it is difficult to properly identify the higher order rings and we subsequently limit our observations and calculations to the first order rings.
The observations of radii of the first order rings made for a set of acceleration (anode) voltages - i.e. different wavelengths of electron beam one can obtain two graphite planes spacing values : d_1, d_2 - Fig.3.

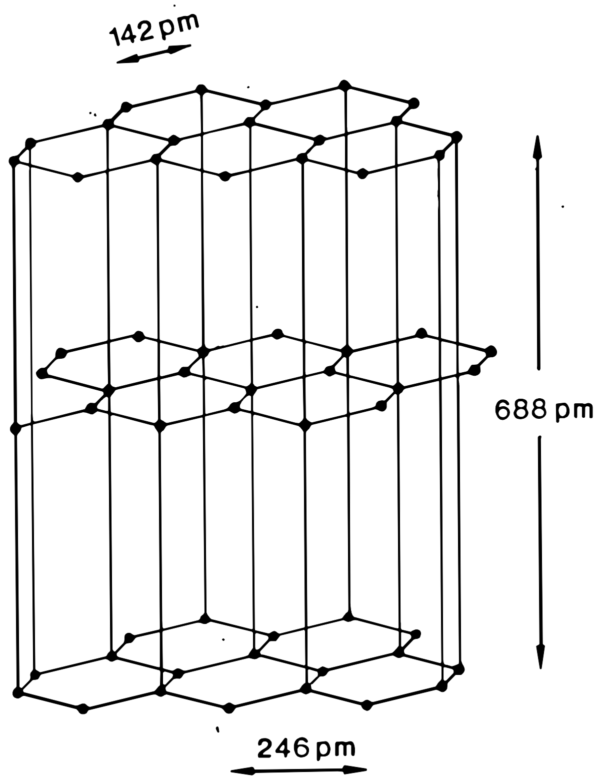

Fig.2. Crystal lattice in graphite

MEASUREMENTS

1. Check out connections of the terminals of the electron diffraction tube to the power supplies – compare it with Fig.1.(H, C, G1, G2, G4).
2. Connect the high voltage - U_A - to the anode terminal -G_3.
   Ask instructor for approval of the connections !!
3. Adjust the blocking voltage - U_B - G1 value above the midpoint.
4. Turn on and adjust the focusing voltages G2, G4 at minimal value.
5. Turn on the high voltage anode supply - G3.
6. Adjust the anode voltage at 4 kV.
7. Slightly decrease the blocking voltage U_B until the sharp well defined diffraction rings of the first order appear.
8. Determine carefully the angle 2α for the two diffraction rings - $2\alpha_1$, $2\alpha_2$.
9. Record the anode voltage - U_B - and angles $2\alpha_1$, $2\alpha_2$. in the data table.
10. Repeat the procedure of steps 6-9 for the series of 10 anode voltage values with 0.5kV step (each time adjust the blocking voltage - U_B - as well).
    Record all results on the data sheet.

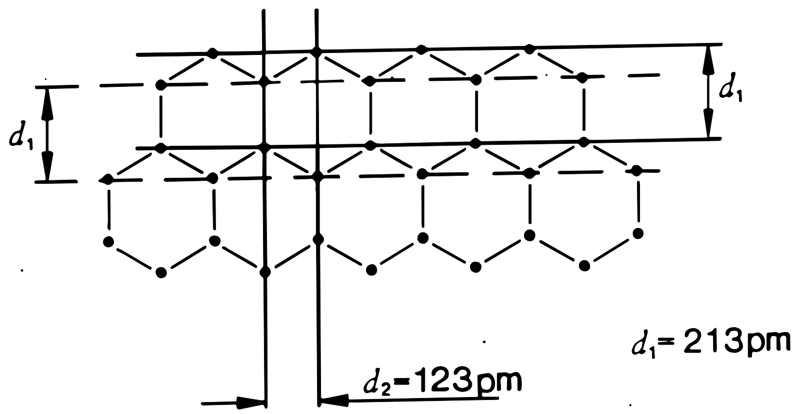

Fig.3. Graphite planes for first two interference rings

CALCULATIONS AND PRESENTATION OF RESULTS

1. Calculate from Eq.3. the wavelength of the electron wave from the anode voltage values. Complete the data table.
2. Calculate radii of the rings from the angle α values (see Eq. 6.)
3. Plot a set of - $r_{1,2}(\lambda)$ dependencies for both first order rings (separately).
4. Calculate for each - $r_1(\lambda)$, $r_2(\lambda)$ curve the slope - A_i - from the linear regression
   Calculate from obtained - A_1, A_2 values the lattice constants - d_1, d_2
   in accordance with Eq. 7. (for $n = 1$) - Eq.8.:

$$A_i = \frac{2R}{d_i} \qquad (8)$$

with : $R = 65 \cdot 10^{-3}$ [m]

ANALYSIS AND INTERPRETATION

1. Discuss the linearity of the established $r(\lambda)$ approximations.
2. Compare established - d_1, d_2 inter-planar spacings in graphite with literature data (see fig.3).

DATA TABLE 1.

$2\alpha_1$ [m] first ring angle	r_1 [m] first ring radius	$2\alpha_2$ [m] second ring angle	r_2 [m] second ring radius	U_A [V] anode voltage	λ[m] wavelength

REQUIREMENTS

1. Material waves. De Broglie equation.
2. Structural lattices in crystals (general information).
3. Bragg reflection of the electron beam from the crystal lattice.
4. Description of the experimental method.