

Electron Diffraction Lab—Measuring interatomic distances between scattering planes

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The purpose of this lab is twofold. The first objective of this lab is to demonstrate the wavelike properties of an electron, namely, the deBroglie wavelength. The second objective is to use these wavelike properties to determine the interplanar spacing between scattering planes in a polycrystalline graphite lattice. Monoenergetic electrons are directed at a graphite target having random orientations of two primary scattering planes labelled d_{10} and d_{11} . Bragg diffraction of the electron beam (elastic scattering) occurs for crystals when their planes are in the proper orientation. The Bragg scattering angle (θ) at various accelerating voltages can be fit to determine the interplanar spacings.

I. BACKGROUND

In 1912 the German physicist Max Von Laue suggested that regularly spaced atoms in a crystal separated by ~ 0.1 nm could be used as a diffraction grating for X-rays. The use of crystals to diffract X-rays was developed by W.L. Bragg and his father W.H. Bragg. Bragg diffraction is discussed in your textbook (Modern Physics, 3rd edition, Kenneth Krane). The primary equation to remember is the one describing the constructive interference (and elastic scattering) between adjacent planes of crystals:

$$2d \sin \theta = n \lambda$$

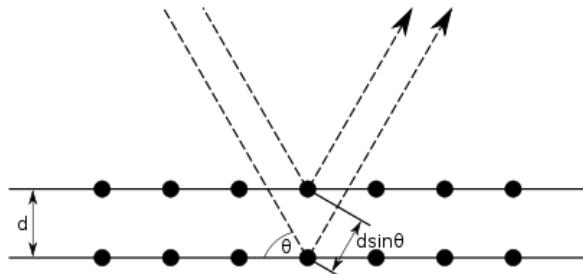


FIG. 1. Bragg diffraction occurs when plane waves with identical wavelengths scatter off adjacent planes of atoms and the path length difference between the two paths is equal to an integer multiple of the wavelength. For electrons, the wavelength is the deBroglie wavelength. Also note that the Bragg angle θ is measured with respect to the surface of the crystal.

There is a wonderful website from fiu.edu that I encourage you to read. The experimental apparatus described in this website is very similar to ours. Furthermore, the physics describing the experiment is very carefully developed and it is “spot on.” The website can be found at the following location.

II. THE THEORY

The principle behind electron diffraction is that a beam of monoenergetic electrons can act like electromagnetic waves (i.e., X-rays) when they interact with the surface of a crystal. In this particular experiment, the crystal is hexagonally-shaped graphite and is shown in Fig. 2. Two diffraction planes are shown as dashed lines in the figure with interplanar spacings d_1 and d_2 .

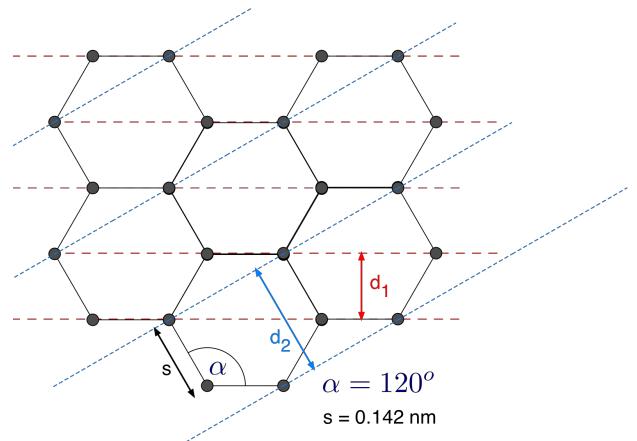


FIG. 2. The structure of graphite with Bragg planes shown in red and blue. The interatomic distance s is 0.142 nm. The accepted values for d_1 and d_2 are 0.123 nm and 0.213 nm. The above figure is courtesy of fiu.edu.

For a single crystal, constructive interference occurs when the Bragg condition is met:

$$n \lambda = 2d \sin \theta \quad (1)$$

where d refers to either d_1 or d_2 , and θ refers to the grazing angle measured with respect to the Bragg planes shown in Fig. 1.

III. THE EQUIPMENT

The apparatus is shown in Fig. 3. Electrons are formed by thermionic emission from a heated filament (4) inside the cathode and are accelerated towards the graphite target (9) by a potential difference V_a between the cathode and anode (target). The kinetic energy K of the electrons as they reach the target is

$$K = \frac{p^2}{2m_e} = e V_a \quad (2a)$$

Using the deBroglie relationship $p = h/\lambda$, we find

$$\lambda = \frac{hc}{\sqrt{2m_e c^2 e V_a}} \quad (2b)$$

Substituting the values for the constants, the deBroglie wavelength as a function accelerating voltage V_a is

$$\lambda(nm) = 1.227/\sqrt{V_a} \quad (2c)$$

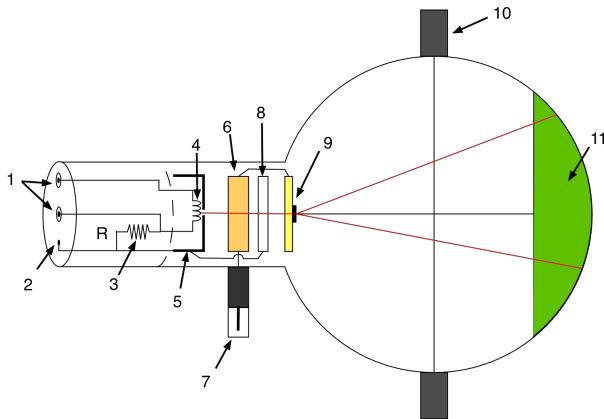


FIG. 3. Overview of the electron diffraction tube. (1) 4-mm socket for the filament heating supply, (2) 2-mm socket for cathode connection, (3) internal resistor, (4) filament, (5) cathode, (6) anode, (7) 4-mm plug for anode connection (HV), (8) focusing electrode, (9) polycrystalline graphite grating, (10) Boss support, (11) fluorescent screen. The above figure is courtesy of fiu.edu.

IV. PROCEDURE

You will find more information regarding the experimental procedure in the description on my website (MP-2). The procedure section in this document accurately describes the necessary steps for producing the *double-ring* image that you will measure on the fluorescent screen. Two prominent rings should appear around the central spot. The inner ring is used to determine the d_{10} interplanar spacing (d_1) while the outer ring is used to

determine the d_{11} spacing (d_2). The electrons are scattered in the same manner as Bragg Diffraction; however, the scattering angle with respect to the electron beam is 2θ . The value of θ can be found from Fig. 4 and the following equations.

$$\tan 2\theta \approx 2\theta = \frac{D/2}{L} \quad (3a)$$

$$\lambda = 2d \sin \theta \approx d 2\theta \quad (3b)$$

$$1.227/\sqrt{V} = d 2\theta = d \left(\frac{D/2}{L} \right) \quad (3c)$$

Using Eq. 3c one can calculate $1/\sqrt{V}$ versus D and finally obtain a relationship between the *diameter* and the *voltage*.

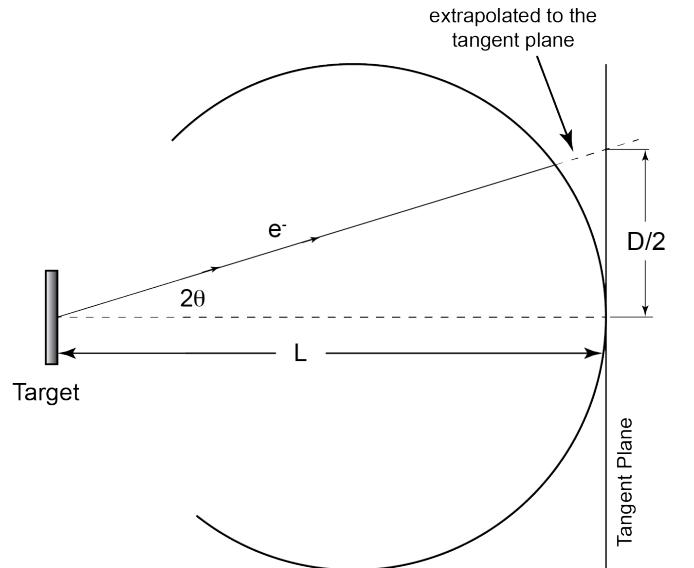


FIG. 4. The geometry of the vacuum tube containing the electron beam, the graphite target, and the fluorescent screen are shown in the figure. In our experiment L is 0.140 ± 0.003 m to the *outside* of the glass, the radius $R = 66.0$ mm, and the thickness of the glass is 1.5 mm.

In order to determine the interplanar spacings d_{11} and d_{10} , the diameter of the inner and outer rings must be recorded as a function of the accelerating voltage V_a . This is shown in Figs. 3a and 3b in the MP-2 writeup.

V. ANALYSIS

The goal is to construct a plot similar to the one shown in Fig. 3b in the MP-2 writeup and fit the straight lines to the *inner* and *outer* data. Decide whether you want to plot $1/\sqrt{V_a}$ vs. D , or D vs. $1/\sqrt{V_a}$. After rewriting Eq. 3c for D versus $1/\sqrt{V}$, this equation can be used

to fit the data collected at voltages between 2,000 and 5,000 volts. Likewise, the resulting slope from the fit will be related to $1/d$ or d depending upon which variables you plot in the x and y direction.

VI. IMPORTANT CONSIDERATIONS

- **Be careful.** You will be using high voltage in this experiment.
- Make sure you read the “Practical Precautions” described in the MP-2 writeup. In particular, pay special attention to the maximum current you should allow on the target, no more than 0.20 mA.
- Again, if you are unsure about operating the apparatus, please ask for assistance. The equipment is moderately expensive; however, your health and well-being are more important.
- **Don’t forget** to do your error analysis. You will need to do the error analysis of a straight line fit, and afterwards propagate the uncertainties correctly to quote your final answer in the following format:

$$d_{10} = \text{_____} \pm \delta d_{10}$$

Do the same for d_{11} .

- Finally, compare your answers to the accepted values for d_{10} (a.k.a d_2) and d_{11} (a.k.a d_1), 0.213 nm and 0.123 nm respectively.

Other interplanar spacings in graphite are shown in

Fig. 6 at a NIKHEF website (High Energy Physics Lab in Amsterdam). Other descriptions of electron diffraction experiments can also be found at the CERN site.