Demonstration of Electron Diffraction

In 1926 De Broglie proposed his theory of wave-particle duality, predicting the phenomenon of electron diffraction. This wave-like property of electrons was first observed by George Thomson in 1927 (George was the son of physicist J. J. Thomson, who had discovered the electron as a particle some years earlier). George Thomson was awarded the Nobel Prize in 1937 for his discovery of electron diffraction.

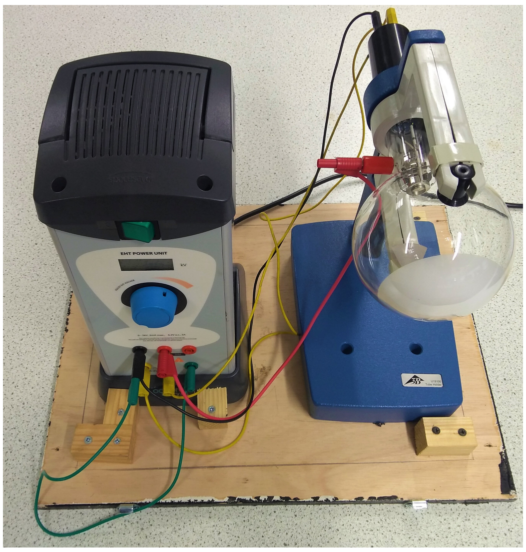
You are going to carry out an experiment similar to the one performed by Thomson. The experiment will investigate how electrons, when accelerated across a potential and passed through a thin layer of graphite, interfere with each other and form an interference pattern, similar to rays of light passing through a diffraction grating. From observing this phenomenon, the "de Broglie wavelength" of the electron can be calculated and used to determine the lattice spacing of the carbon atoms in a thin layer of graphite.

Safety

High Voltage: This experiment uses a high voltage of up to 5kV. The HV is fully enclosed, but the apparatus should be set up in advance by a member of staff. Please do not handle or remove any of the cables or touch the electronics once the equipment is powered up.

Fragile equipment: The fine beam tube is an evacuated glass vessel and presents a danger of implosion. The apparatus should only be moved in its protective box. Please do not handle the beam tube during the experiment.

Set up instructions for staff.



Instructional videos on how to set up this experiment are available on the Lancaster Physics/ Outreach/ Lab in a Box webpage. Please fully assemble the apparatus before powering it up.

Unboxing: The apparatus arrives in a large wooden box, which must be opened by unfastening the straps and then lifting the top of the box vertically up.

Figure 1 (above) and Figure 2 (below, next page): A photograph showing the fully assembled electron diffraction apparatus pictured from both front and back.

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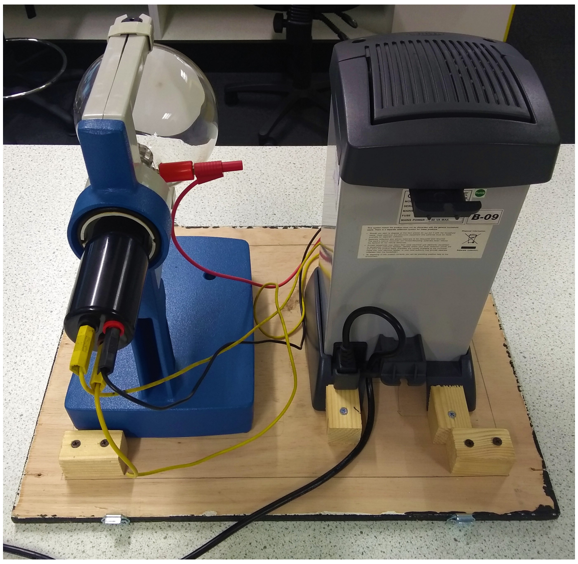

The beam tube is secured within a protective cover, and should be removed from the box with caution. The tube should be fastened in its holder, and its base should then be attached. Once the tube is securely in place, please connect up the cables as shown in the figures provided.

Once the apparatus is fully assembled, it can be powered up using the green switch on the front of the EHT power unit. High voltage settings in the range **3.8-4.9 kV** should produce distinct diffraction patterns. It is advised that the apparatus is switched off when not in use to preserve the fluorescent film on the glass.

Background

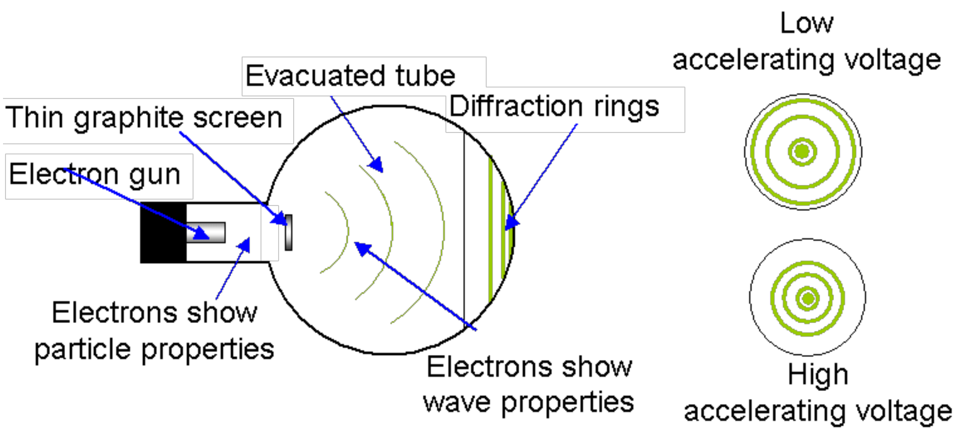

Figure 3: Electron diffraction rings produced within the beam tube.

The beam of electrons is produced by an "electron gun", which is a cathode filament that produces electrons when heated. The electrons are accelerated towards the anode by the application of a high voltage. The voltage can be adjusted, which in turn changes the kinetic energy of the electrons. The electrons pass through a thin layer of graphite, which acts as a diffraction grating. The beam is then incident on the fluorescent screen. The resulting diffraction pattern should be visible on the screen as two distinct circular rings. Changing the voltage should change the radius of the two rings as seen in Figure 3.

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Task 1	Switch on the apparatus and check that you can see the green rings within the specified range. You may need to darken the room to clearly see the rings. Next, vary the high voltage and measure the diameter of the rings for a range of voltages.

Question 1

Use the Vernier calipers provided to precisely measure the diameter of the diffraction rings (please ask a member of staff if you need help using the Vernier calipers). Divide this by two to find the radius.

Consider the questions below:

1. Consider the thickness of the rings. How will you accurately define the diameter of each ring?

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2. What will you use as your uncertainty in the diameter measurement?

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Record your measurements and their uncertainties in the table below:

Voltage [kV]	Ring 1 Radius r_1 [mm]	Ring 2 Radius r_2 [mm]

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Question 2

To understand our measurements in terms of the diffraction of waves, we need to derive an expression for the *de Broglie* wavelength of our electron beam.

The kinetic energy of electrons accelerated by a high voltage V can be found from the principle of energy conservation as follows:

$$eV = \frac{1}{2}mv^2$$

In this equation, e and m are the electron's electric charge and mass, and v is the velocity of the electron beam.

The *de Broglie* wavelength of a particle is related to its momentum by the following expression:

$$\lambda = \frac{h}{p}$$

The physical constant h is known as *Planck's constant*.

By combining these equations together, derive an expression for the *de Broglie* wavelength λ in terms of the applied high voltage V and the physical constants e, h and m.

(Hint: you'll need to use the known relationship between the momentum and velocity of a particle)

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Answer: $\lambda = \frac{h}{\sqrt{2meV}}$

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Question 3

For each of your measurements, use the accelerating voltage to determine the momentum and *de Broglie* wavelength of the electrons.

You'll need the following physical constants for your calculations:

Electron mass: $m_e = 9.11 \times 10^{-31}\ kg$
Electric charge: $e = 1.60 \times 10^{-19}$ C
Planck's constant: $h = 6.63 \times 10^{-34}\ Js$

Record your answers in the table below, including uncertainties.

Voltage [kV]	Momentum [m×kg/s]	*de Broglie* Wavelength [nm]

Task 2

A thin layer of graphite acts as a diffraction grating in this experiment. In this task, we'll use the measured radii of the diffraction rings, coupled with the calculated *de Broglie* wavelength of the electrons, to determine the lattice spacing of the graphite. As you work through the calculation below, remember to continue your error analysis and to convert all your variables to SI units.

Question 4

First consider the following questions:

1. Why do you think graphite makes a good diffraction grating in this experiment?

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2. The presence of two different diffraction rings means that the graphite layer has two different characteristic lattice spacings. Figure 4 shows the known crystalline structure of graphite. Using this figure, explain why graphite has a pair of different lattice spacings.

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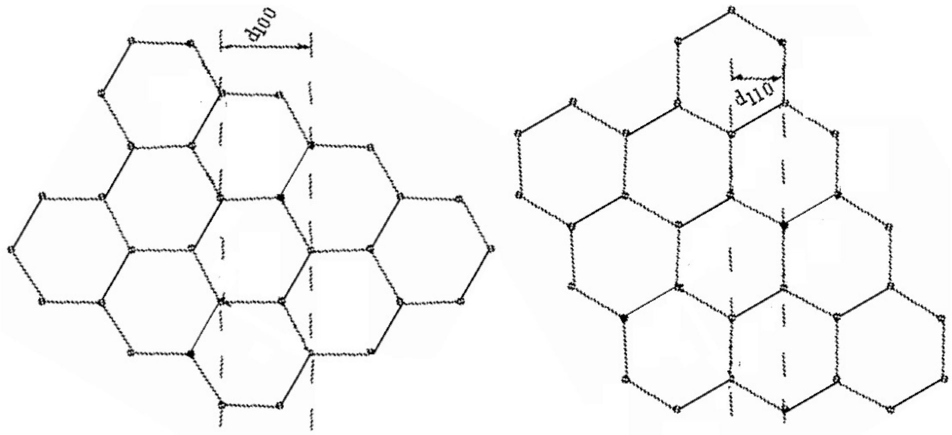

Figure 4: Representation of the graphite's crystal lattice structure.

The *de Broglie* wavelength λ of the electron beam can be related to the lattice spacing d by the following expression:

$$\lambda = \frac{d\,r}{L}$$

where r is the measured radius of the diffraction ring and $L = 135\ mm$ is the distance between the graphite layer and the fluorescent screen. Using this equation, calculate the lattice spacings in the graphite layer, including uncertainties.

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Record your answers in the table below:

De Broglie Wavelength [nm]	Ring 1 lattice spacing d_1 [m]	Ring 2 lattice spacing d_2 [m]

Accepted values:

Ring 1 lattice spacing: $d_1 = 2.4612\times 10^{-10}\ m$.

Ring 2 lattice spacing: $d_2 = 6.7079 \times 10^{-10}\ m$.

Question 5 Was the experiment successful? What was the largest source of error? How could you improve your results? Record your thoughts below.

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