

ELECTRON DIFFRACTION EXPERIMENT

BEFORE LAB:

Look up both "electron diffraction" and "double-slit interference" in either your Modern Physics text or an Introductory Physics text. Take good notes. Read these instructions before class as well.

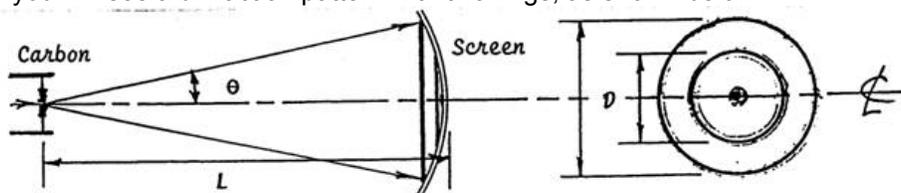
INTRODUCTION:

In 1924 Louis deBroglie suggested that particles could have wave properties in the same way that light has particle properties. Clinton Joseph Davisson and Lester Germer, in 1925, and George Paget Thomson in 1927, -- the son of the very same J. J. Thomson who discovered that electrons behave as *particles* -- showed separately that electrons do indeed behave as waves, by diffracting them from crystalline surfaces. Today, you will do the same.

EXPERIMENT:

A calculation using deBroglie's equation ($\lambda = h/p$) shows that electrons accelerated through a potential difference of 4 kV would have a wavelength of about 0.02 nm. Although it is impossible to produce a diffraction grating with rulings of approximately $d = 0.2$ nm (to produce measureable interference), we have available natural "gratings" in the form of crystals. The tube you will use has a graphite (carbon) polycrystal with an appropriate inter-atomic distance. You will be determining that distance, d .

If the material we were using as a target were a single "one-dimensional" crystal, we would see an electron diffraction pattern consisting of vertical lines on a screen. If it were a perfect two- or three-dimensional pattern, we would see a two dimensional dot pattern on our screen. Instead, it is not a single crystal, and so you will see a diffraction pattern with two rings, as shown below:



(There are *other* rings, but they will be too dim and at angles too large for us to observe.) Measuring the relation between accelerating voltage and diffraction ring diameter will allow us to determine the interatomic distances in the carbon foil inside.

To pull those distances out of our raw data, let's start with the deBroglie wavelength of a particle, $\lambda = h/p$. For non-relativistic electrons ($KE \ll mc^2$), we also have $p = mv$. The individual electrons' kinetic energy is equal to $KE = \frac{1}{2} mv^2$. This kinetic energy is the result of an accelerating voltage, V_a , and is equal to eV_a .

Question 1: Derive an expression for electron wavelength as a function of accelerating voltage.

Question 2: In this experiment, the accelerating voltage is limited by our power supply and multimeter to no more than 2kV. Can we ignore relativity? Why?

The diffraction rings follow the same physics as the interference maxima in a two-slit or multiple-slit interference pattern. Find the equation -- in a physics textbook -- in terms of the slit distance, d , the angle, θ , of the " n^{th} " interference maximum, and the wavelength, λ . Note that for small angles, $\sin \theta = D/2L$.

Question 3: Derive an expression for D as a function of V_a . Put this in a form so that a linear graph can be made. Verify with the instructor that your result is correct before continuing with the experiment.

Connect the tube into the circuit shown on the accompanying diagram, paying special attention to the precautionary notes. Do not turn on the power supply until your circuit has been checked by an instructor, and when you do turn it on, let the filament warm up for 1 minute before increasing V_a . Turn

up V_a until you have a diffraction pattern, adjusting the bias voltage so that the current never exceeds 0.175mA. Use an external desktop voltmeter to measure V_a up to 2kV.

Measure the *inner* diameters of the two most visible rings, D_{inner} and D_{outer} for several values of V_a , and plot your results in such a way that you get a linear graph. Plot as you go, so as to determine the best strategy for amassing good data points. When you are done, use appropriate software to find the slope -- *and uncertainty* -- of your straight line fit. From this you can determine the ratio of the two values -- *including uncertainty* -- and their actual magnitudes.

ANALYSIS:

Here comes the hard part. How do you interpret two different values for the interatomic spacing? Both of these numbers correspond to the distance between planes of atoms in the carbon (graphite) lattice. If this lattice were a simple cubic lattice -- atoms arranged like the corners of cubes -- this would be simpler, but not trivial. Your instructor has laid out some two-dimensional "lattices" on the lab bench. Take one and inspect it. If you look at it straight on, you will observe that the "atoms" line up behind each other in simple rows. But rotate it a little and you will see different atoms start to line up behind the atoms in front. From this angle, the distance between the rows of atoms has changed. It turns out that the ratio of the distance between planes in the first and second examples is 1.414 : 1 or $\sqrt{2}$:1.

Graphite consists of two-dimensional sheets loosely bound to other parallel two-dimensional sheets. Within each sheet, the atoms are arranged in a hexagonal lattice. (See attached sheet.) Your first task is to locate the planes. Take the attached sheet with the hexagonal lattice on it and find two different sets of planes. Notice that the distance between planes has to repeat itself exactly. Most likely you have found the "(10)" and the "(11)" planes, which differ by a factor of $\sqrt{3}$, or 1.732 in size. Measure these two interplanar distances carefully on your sheet, and compare them. Do they differ by a factor of $\sqrt{3}$?

Finally, calculate the two "d"s from your data, using the slopes you calculated from your raw data. Don't forget to calculate the uncertainties. From these, calculate the closest distance between two atoms in the graphite. You can estimate the *approximate* spacing of carbon atoms in the crystal knowing that 12 grams of carbon contain 6×10^{23} atoms and the density of carbon is about 2 grams/cm³. Does this result agree with your earlier measurements? Bear in mind that the graphite crystal is not cubic, so this is only a crude estimate.

Hexagonal lattice:

<http://it.stlawu.edu/~koon/classes/221.222/221L/Hexagonal.gif>

