ARIEL UNIVERSITY

Faculty of Physics - 3 agosto 2021

modern physics lab course

Electron Diffraction experiment.

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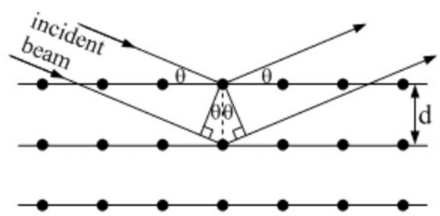
Indice

1 Objective

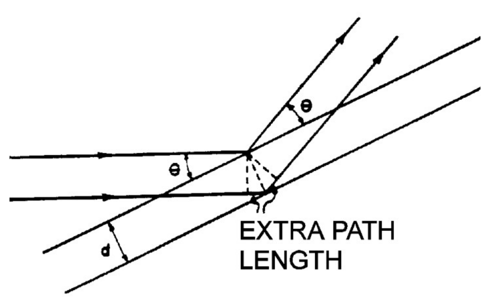
- Provide proof to the De-Broglie relationship .
- Observe diffraction of the beam of electrons on a poly-crystalline material and to find atomic-spacing of graphite.

2 Theoretical introduction

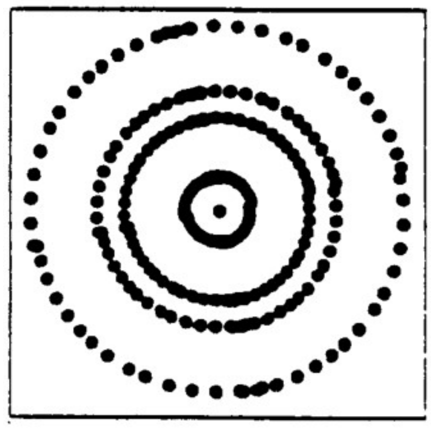
This experiment is a demonstration of the wave nature of the electron, and provides a confirmation of the De-Broglie relationship $\lambda = \frac{h}{p}$ where $\lambda[m]$ is the wavelength of a moving electron , and $p[N * s]$ is the momentum of the electron and Planck's constant $h = 6.625 \cdot 10^{-34}[J \cdot S]$. A formula Which describes that moving electrons that are expected to display particle like behaviour , also exhibit wave like behavior. In order to see if electrons really do act like waves we will perform a diffraction experiment and attempt to see if the results match expected behaviour of light or do they match expected behaviour of particles. Consider a poly crystalline graphite film deposit on a copper grating as shown in the figure :



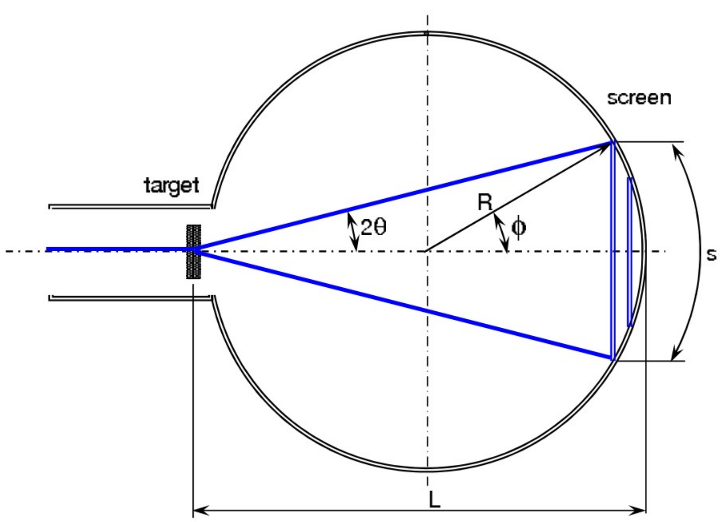
These are the planes of an atom in crystal that are separated by a distance d. The electron acts like a wave, therefore the electron "waves" will reflect from these planes and exhibit an interference pattern , which is an analogous case to light interference. Suppose the electron is accelerated via DC voltage , the momentum can be calculated by $K = \frac{1}{2}mv^2 = \frac{p^2}{2m} = e \cdot U_A$ where U_A is the acceleration voltage in volts, and $m = 9.109 \cdot 10^{-31}[Kg]$. We can use the De-Broglie formula and achieve the following result for wavelength $\lambda = \frac{h}{\sqrt{2m_e U_A}} = \frac{1.11}{\sqrt{U_A}}[nm]$. In order to discuss diffraction let us use the condition for constructive interference : the path length difference will be an integer multiple of wave length . This is also known as Bragg's law : $2d \sin\theta = n \cdot \lambda, n = 1, 2, 3$ 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).



Diffraction from poly crystalline material is not the same as diffraction from a single crystal. A poly crystalline material is a large number of crystals that are randomly oriented . The bond between individual layers is broken so that their orientation is random . The electron beam spreads out as a cone , and the interference pattern is ring like. Looking over the system of the experiment from above, one would expect to see concentric rings :



The Bragg angle θ can be calculated from the radius of the interference ring : $\alpha = 2 \cdot \theta$, $\sin 2\alpha = \frac{r}{R}$ where $R = 65[mm]$, radius of the glass bulb. $\sin 2\alpha = 2 \sin \alpha \cos \alpha \approx 2 sin\alpha$ for small angles of θ we obtain $sin2\alpha = sin4\theta \approx 4sin\theta$ With this approximation we obtain : $r = \frac{2Rn\lambda}{d}$ The screen is made of fluorescent material which glows when hit by the electrons , and the radius r is visible and can be measured with a ruler . Therefore being able to measure the radius of the interference rings and plot the results in a program will obtain the following slope : $P = \frac{2R}{d}$ and obtain results for the wave length of the electron, providing information whether De-Broglie relationship is correct . Provided that the results match the theory, the distance between planes in the graphite is found by : $d = \frac{2R}{P}$



3 Setup Procedure

Setup the experiment
• K is connected to the ground socket of the power supply.
• H sockets on the electron diffraction tube are filament voltage and they
are connected to the 6.3V AC sockets of the power supply.
• The socket of G3 is connected to a resistor of 10MΩ which is connected to a 10kV power supply.
• G1 is connected to DC power supply of 0 to -50V.
• G2 is connected +300V of DC power supply.
• G4 is connected to DC power supply of 0V to +300V
• All the negative sockets of the DC power supply are connected to the ground socket.
• We used the voltmeter of the kV power supply in order to measure the voltage of G3. If there isn't a voltmeter in the power supply it is necessary to connect in parallel a voltmeter that can measure kV.

4 Experiment Procedure

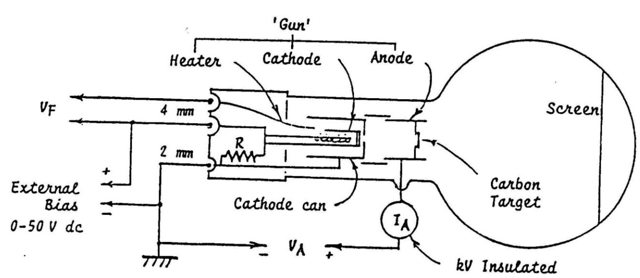
1. For voltage of 4200V, we measure the radius of the first ring and the second ring.
2. We decreased the voltage in 400V and measured the radius of each ring, measurement range is 2200V to 4200V.
3. We did the measurement twice and calculated the mean value of each radius.
4. Using equation we can calculate the measured electrons wave length.
5. Using equation

$$\frac{m\lambda}{d} = \frac{r}{2R}$$

we calculate the theoretical electron's wave length.

6. We plot a graph of λ_{theory} as function of$\lambda_{measured}$ in order to see the deviation between the two wave lengths.

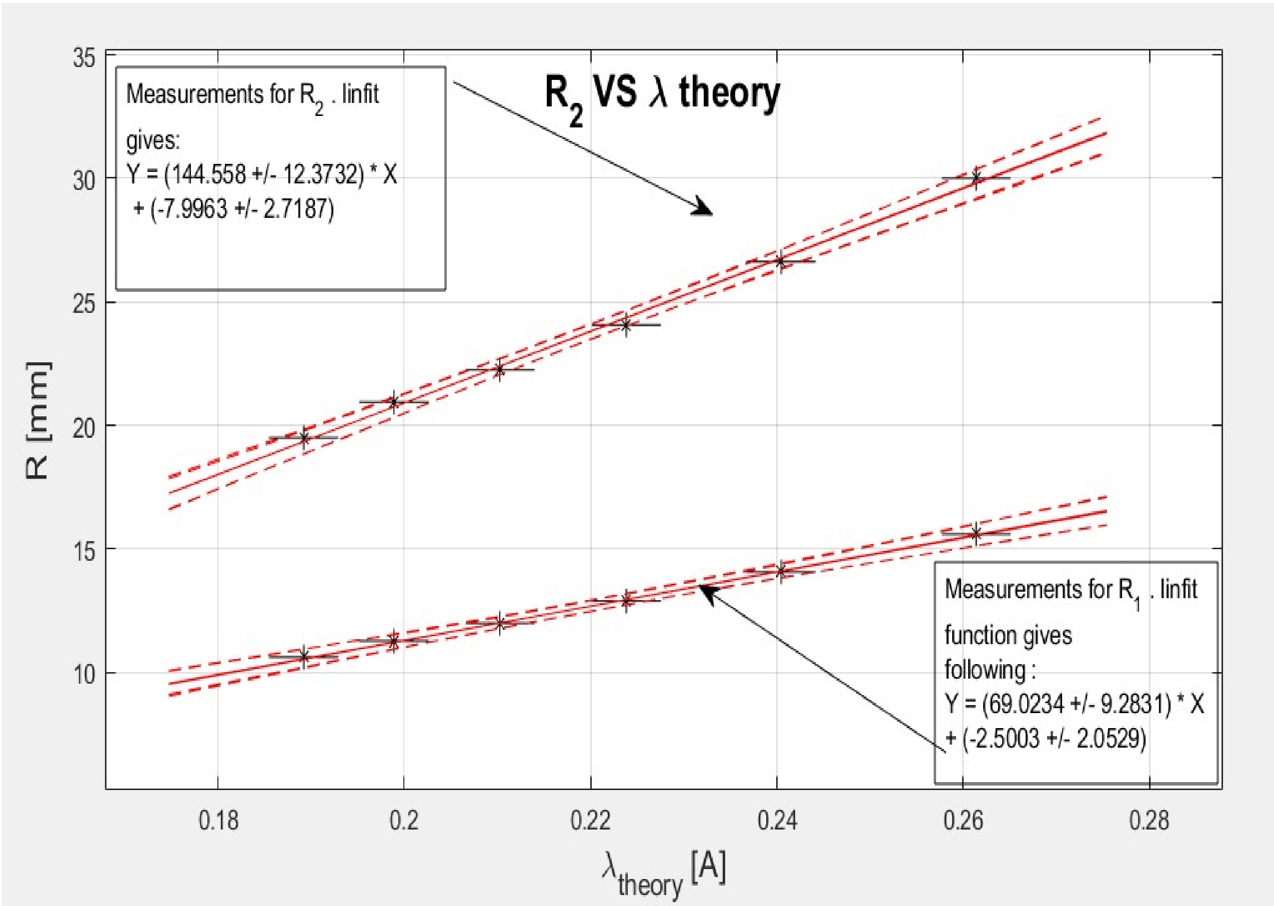
The electrons are accelerated via electron "gun" , as seen in following figure :



The voltage V_A is the voltage that accelerates the electrons, this voltage is varied between $4.2[kV]$ in intervals of 400[V] down to 2.2[kV], each voltage translates to kinetic energy which is momentum, corresponding to a De-Broglie wavelength, and corresponding to two visible interference rings seen on the fluorescent screen. The radius of the interference rings allows for a second calculation of wavelengths, the data is sorted in the table:

Voltage[V]	$\lambda_{De-Broglie[Ang]}$	$R1_{cm}$	$R2_{cm}$	$\lambda 1_{Diff[Ang]}$	$\lambda 2_{Diff}[Ang]$
4200 ± 50	0.189176 ± 0.002252	10.625 ± 0.5	19.5 ± 0.5	0.167638 ± 0.015778	0.177667 ± 0.009111
3800 ± 50	0.198883 ± 0.002617	11.275 ± 0.5	20.95 ± 0.5	1.77894 ± 0.015788	0.190878 ± 0.009111
3400 ± 50	0.210257 ± 0.003092	12 ± 0.5	22.25 ± 0.5	0.189333 ± 0.015778	0.202722 ± 0.009111
3000 ± 50	0.223836 ± 0.003731	12.9 ± 0.5	24.075 ± 0.5	0.203533 ± 0.015778	0.219350 ± 0.009111
2600 ± 50	0.240438 ± 0.004625	14.075 ± 0.5	26.625 ± 0.5	0.222072 ± 0.015778	0.242583 ± 0.009111
2200 ± 50	0.261384 ± 0.0059421	15.6 ± 0.5	30 ± 0.5	0.246133 ± 0.015778	0.273333 ± 0.009111

The indices for R1,R2,$\lambda 1_{Diff}, \lambda 2_{Diff}$ correspond to the accepted inter planar values from the literature. $d_1 = 2.13[Ang], d_2 = 1.23[Ang]$ there is no perfect correlation between measured wave lengths and the the theoretical calculation. Overall the De-Broglie equation gives a good approximation for the wavelength of the electron. Electrons obviously exhibit wave like behavior or no diffraction pattern would appear. The error on voltage is taken to be 100[V] since that is the last digit the DC source shows, and the voltage error affects the $\lambda_{De-Broglie}$ error. The error on radius is systematic and taken to be 0.5[cm] for every measure, this systematic error also affects the systematic error on λ_{Diff}



As previously mentioned the wavelength can be plotted versus the measured radius of the rings giving two slopes $m_2 = 144.558 \pm 12.3732 = \frac{2R}{d_1}$ and $m_1 = 69.0234 = \pm 9,2831 = \frac{2R}{d_2}[\frac{mm}{Ang}]$

d_1 Theory	d_1 Measured	d_2 Theory	d_2 Measured
$2.13[Ang]$	$(2.17, 2.845)[Ang]$	$1.23[Ang]$	$(1.083, 1.2866)[Ang]$

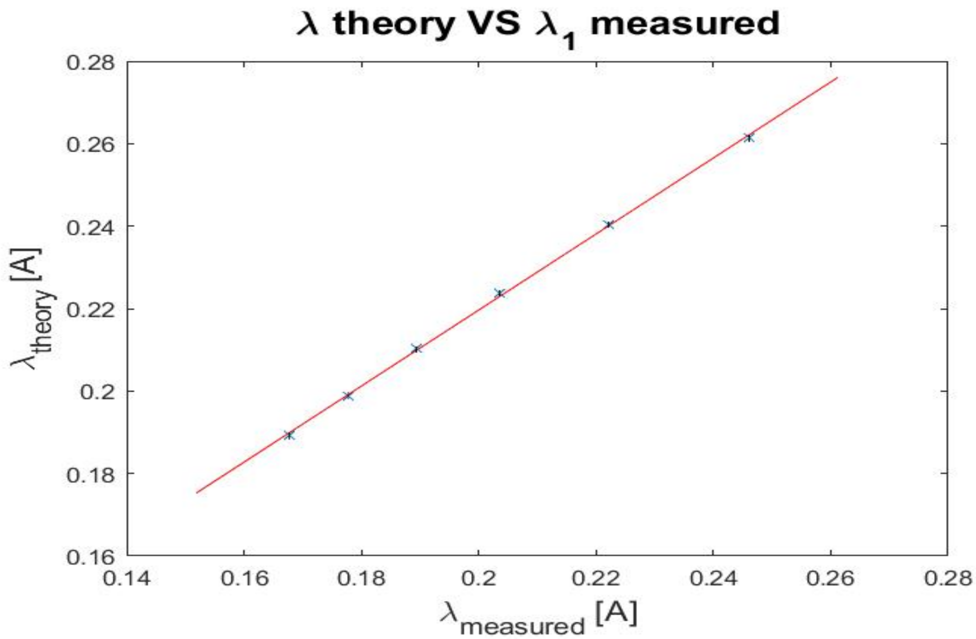
Where the measured values in the table show the possible interval of inter planar distance according to the measure. R is the radius of the glass bulb. The results correlate with the accepted theoretical value for inter planar spacing.
From the graph's slope we can calculate d1 and d2 and using the theoretical values of d1 and d2 we can calculate error estimation.

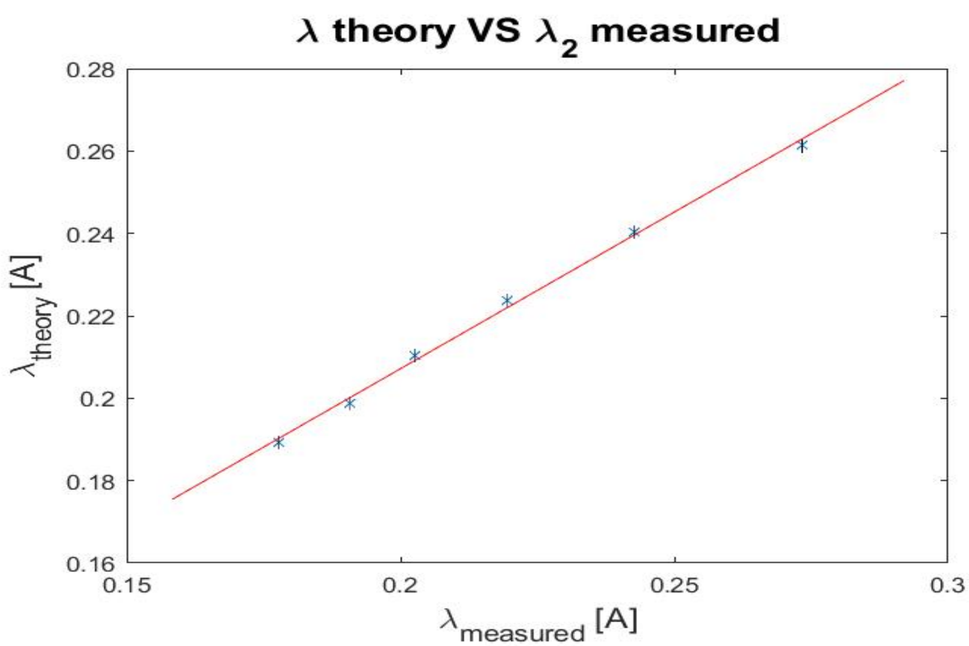
It is noticeable that the correlation between the expected value of the wave length and the measured one are at a ratio close to one. Using the two measurements and plotting them we get :

$$\lambda_t = 0.9221 \cdot \lambda_m + 0.03523$$

$$R^2 = 0.9993$$

$$RMSE = 0.001563$$





5 Conclusion

This experiment demonstrated the wavelike behaviour of electrons. Looking on the electron like a wave gives tools to perform interference experiments that are able to provide adequate information on the structure of matter that has inter planar spacing similar to the wavelength of the electron.
The results correlate with the accepted theoretical value for inter planar spacing. De-Broglie's was right indeed and that electrons - or any matter particles act like waves. From that we understand the duality of matter.