Diffraction of Electrons into Two Concentric Rings

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Abstract

This experiment verifies the concept of a beam of light in the form of matter waves in which de Broglie, Davisson, and Germer all made contributions. Interatomic spacing in carbon foil can be found through observation of concentric rings formed by Bragg diffraction of electron “waves”.

Introduction

Clinton Davisson and Lester Germer performed the first experiment ever done involving electrons diffracting with wave-like properties due to a constant voltage in 1927.[1,2] While scattering electrons in order to inspect the properties of metallic surface, a liquid air bottle exploded near their equipment. This accident caused the liquid air to interact with the nickel they were exploring, and since the nickel was at a high temperature, it became significantly oxidized. Davisson and Germer tried deoxidizing the metal with prolonged annealing at various high temperatures in both a hydrogen environment and under vacuum. Once they thought that it was completely deoxidized, they placed the nickel under observation once more only to realize that the electrons scattered from the metallic surface differently from before. Instead of the smooth variations in intensities of scattering angles, the new scattering angles displayed large increases of energy.[3]

When they investigated the source of the alteration, Davisson and Germer discovered that the high temperatures manipulated the polycrystalline structure of the nickel: multiple small crystals turned into a few large crystals. Noticing that the cause for electron diffraction was of the atom arrangement in the crystal, they concluded that the Bragg law applied to their data just like it did with Louis de Broglie’s experiment on X-rays.[3] From his experiment, de Broglie was also able to understand that waves and particles coexisted and that any moving body may be accompanied by a wave.[4] De Broglie’s conclusion on matter waves originated from the thought of electrons forming wave properties in his efforts to solve wave and particle properties of light.[1] Davisson and Germer were able to use de Broglie’s information in order to vary the scattering angles for a given wavelength, along with varying the wavelength, by changing the electron accelerating voltage and, in turn, the momentum, for a given angle.[3]

Unlike diffraction of waves in which the wave spreads out after going through the slit, electron diffraction displays the distinct presence of lines at scattering angles from the diffracted particle-wave. This experiment displays concentric rings from electron diffraction in which a wavelength is derived from the de Broglie relationship.

Experiment

By connecting the electron diffraction tube, Tel 555, to the EHT and regulated power supplies, a beam of electrons is projected toward a thin sheet of carbon in order to obtain two concentric rings. These rings can only be seen in darkness. With the lights off, vary the accelerating voltage until two clear concentric circles are seen in the tube. Focus as necessary using a low voltage source. Use a ruler to measure the diameter of each circle. Repeat at least five trials the same steps only adjusting the current then the voltage for each test. Make a table of the information gathered and for each accelerating voltage find the wavelength through de Broglie's equation:

1) $$\boldsymbol{\lambda = \frac{h}{\sqrt{2emV_a}}}$$

Where h is Planck's constant, e is the electron charge, m is the electron mass, and V_a is the accelerated voltage. Then, with the accelerating voltage, inner and outer diameters of the rings, and the length, L, of the beam of electrons, find inner and outer grating spacing, d, from the equation:

2) $$\boldsymbol{D = \left(\frac{2L}{d}\sqrt{150}\right)\frac{1}{V_a^{1/2}}}$$

On a D by $V_a^{-1/2}$ graph, everything in the parentheses of Equation 2 is the slope. Using the given grating spacing for the inner and outer diameters, find the percent errors when they are compared to the calculated spacing.

Results

The electron diffracting tube gave the outer diameter (D_{outer}) and inner diameter (D_{inner}) in correlation to the accelerating voltage (V_a). Table 1 displays the dependence of diameter size upon accelerating voltage. Using de Broglie's Equation (1), the wavelengths of the electrons at different accelerating voltages are calculated. Data is seen in Table 2. If the waves were electromagnetic in origin, these wavelengths would be grouped as gamma rays in the electromagnetic spectrum.[3]

With the accelerating voltage and diameters found in the experiment and the given electron beam length, L, of 13.5 centimeters, Equation 2 was manipulated into obtaining spacing within the carbon foil's atomic structure inside the tube (Table 1). These were then compared to the given spacing of 1.20 Å for d_1 and 2.06 Å for d_2 as is also shown in Table 1. Then the accelerating voltage and diameters were placed into graph 1.

Discussion

Davisson and Germer's accidental discovery correlated with de Broglie's realizations. Using de Broglie's relationship

3) $$\lambda = h/p$$

along with his Equation (1), they were able to realize that the lower the accelerated voltage and consequently the momentum, the higher the wavelength of the matter waves.[5] In other words, wavelengths have an inversely proportional relationship with the accelerated voltage and momentum. This experiment also displayed that proportionality that Davisson, Germer, and de Broglie all discovered.

Electron diffraction occurring in this experiment appears in the concentric rings displayed on the luminescent screen. These occur when the voltage is high enough that when the electron beam filters through the carbon foil, electrons are dispersed due to the carbon's two-dimensional atomic structure. They will first bounce off the luminescent screen, which contributes the electron scattering by its spacing, and will bounce off at certain angles from there. Then, the electrons will rebound inside the globular tube, making contact with the luminescent screen in a way that two rings form around the central beam, one for each interatomic. The higher the voltage, the sharper and smaller the rings are.

References

1. Beeching, Richard. *Electron Diffraction*, (1936).
2. De Broglie, Louis. *Matter and Light: The New Physics*, (1939).
3. Thornton, Stephen T.; Rex, Andrew. *Modern Physics for Scientists and Engineers*, 3rd Ed. (2006).
4. Anastopoulus, Charis. *Particle or Wave: The Evolution of the Concept of Matter in Modern Physics*, (2008).
5. Fisher, David. *Electron Diffraction Experiment*, (2011).

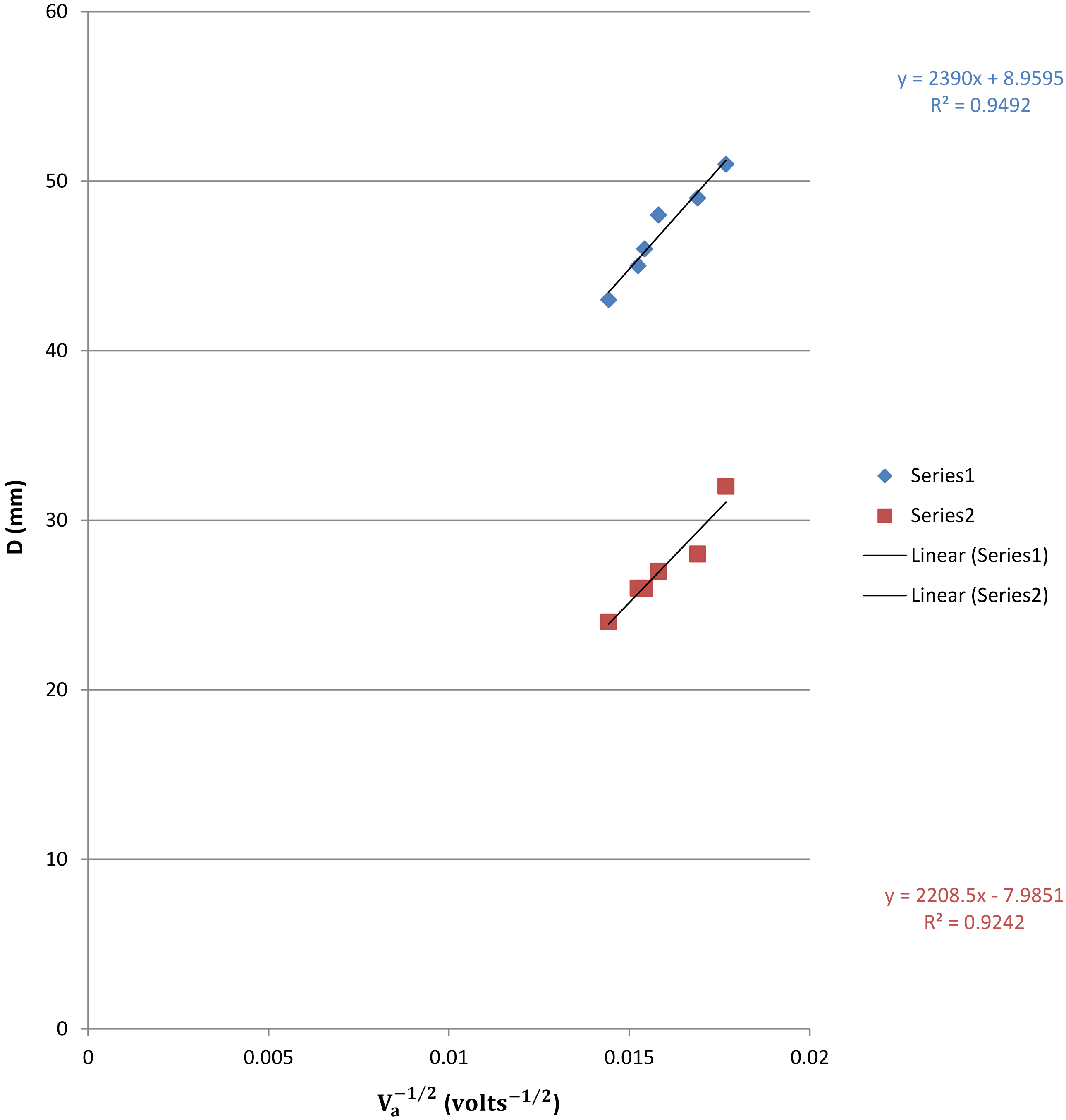
Table 1

V_a (kV)	D_{outer} (mm)	d_1 (Å)	d_1 Percent Error	D_{inner} (mm)	d_2 (Å)	d_2 Percent Error
4.8	43	1.11	7.5%	24	1.99	3.4%
4.3	45	1.12	6.67%	26	1.94	5.83%
4.2	46	1.11	7.5%	26	1.96	4.85%
4.0	48	1.09	9.17%	27	1.94	5.83%
3.5	49	1.14	5.0%	28	2.00	2.91%
3.2	51	1.15	4.17%	32	1.83	11.17%

Table 2

V_a (kV)	λ (m)
4.8	1.78×10^{-11}
4.3	1.88×10^{-11}
4.2	1.9×10^{-11}
4.0	1.94×10^{-11}
3.5	2.08×10^{-11}
3.2	2.17×10^{-11}

Graph 1


60
50
40
30
20
10
0
D (mm)
0
0.005
0.01
0.015
0.02
$V_a^{-1/2}$ (volts$^{-1/2}$)
y = 2390x + 8.9595
R^2 = 0.9492
Series1
Series2
Linear (Series1)
Linear (Series2)
y = 2208.5x - 7.9851
R^2 = 0.9242