Classroom

In this section of *Resonance*, we invite readers to pose questions likely to be raised in a classroom situation. We may suggest strategies for dealing with them, or invite responses, or both. "Classroom" is equally a forum for raising broader issues and sharing personal experiences and viewpoints on matters related to teaching and learning science.

G. P. Thomson's Experiment of Electron Diffraction*

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De Broglie's hypothesis of the dual nature of matter was confirmed experimentally independently by Davisson-Germer and G. P. Thomson. But most of the textbooks (e.g. [1]) discuss Davisson–Germer experiment. In this article, G. P. Thomson's experiment of electron diffraction is discussed.

Introduction

The dual nature of radiation was proposed by Einstein while explaining the photoelectric effect. The idea of dual nature was extended to matter by de Broglie in his doctoral thesis. A few years later, the wave nature of electron was observed in the experiments performed by Davisson–Germer and G. P. Thomson independently. These experiments confirmed that electrons indeed exhibit wave-like characteristics apart from particle characteristics. Though electron diffraction was observed in both these experiments, the details of the experiment differ.

Keywords
Matter waves, electron diffraction, dual nature.

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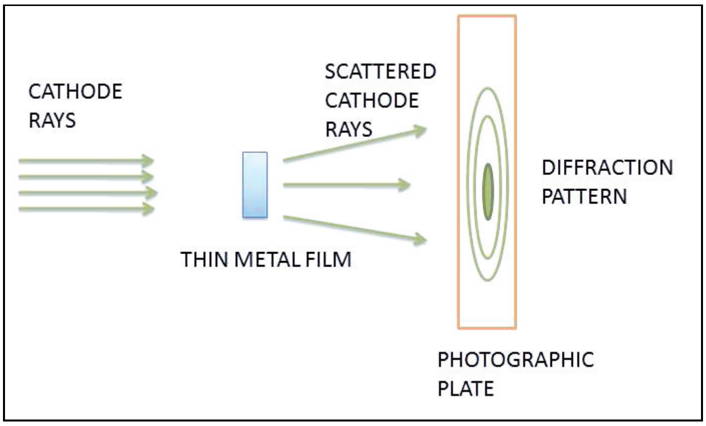

Figure 1. A schematic of Thomson's experiment.

Experimental Details

In G. P. Thomson's experimental setup, cathode rays are generated by an induction coil and directed to a thin film of metal. The film and photograph plate are separated by a distance of 32.5 cm. The photographic film can be moved up and down in front of a screen that can be used to monitor the cathode rays before the photograph is recorded.

In G. P. Thomson's experimental setup [2], as shown in *Figure* 1, cathode rays are generated by an induction coil and directed to a thin film of metal. The film and photograph plate are separated by a distance of 32.5 cm. The photographic film can be moved up and down in front of a screen that can be used to monitor the cathode rays before the photograph is recorded.

Thin films of aluminum and gold were used in the experiment. From the X-ray diffraction study, the lattice constant of aluminum and gold were known. In the case of aluminum, electrons accelerated through a potential of 17.5 kV to 56.5 kV and for gold, electrons were accelerated through a potential of 24.6 kV to 61.5 kV.

The atomic planes in metal plates result in the diffraction of electrons. Bragg's diffraction condition is:

$$n\lambda = 2d \sin\phi \, , \tag{1}$$

where d is the spacing between neighbouring planes, n is the order of diffraction, λ is the wavelength and ϕ is the angle of diffraction. For small angles, Bragg's diffraction condition reduces to

$$\phi = n\lambda/2d \, . \tag{2}$$

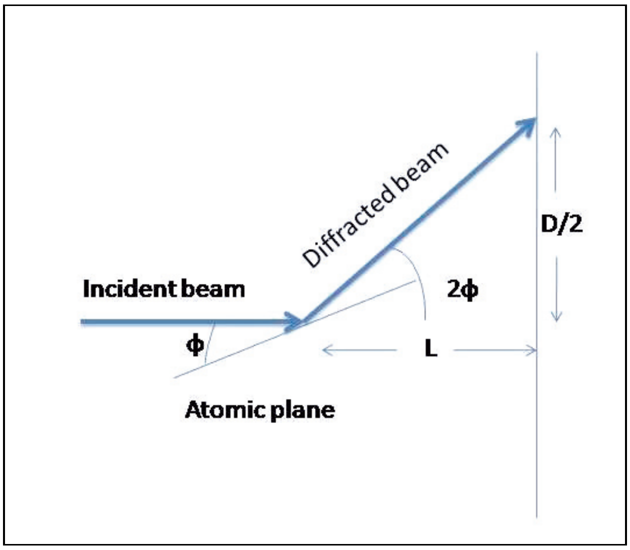

Figure 2. Electron diffraction in Thomson's experiment.

Let D be the diameter of a ring observed in the diffraction pattern on the photographic plate. This diffraction is due to the atomic planes that are at a distance L from the photographic plate. If an electron beam is incident at an angle ϕ, then the diffracted beam makes an angle of 2ϕ with the incident beam as shown in *Figure* 2.

If an electron beam is incident at an angle ϕ, then the diffracted beam makes an angle of 2ϕ with the incident beam.

From the geometry in *Figure* 2,

$$2\phi = \frac{D/2}{L} = \frac{D}{2L} \, . \tag{3}$$

Thus, from (3) and (2),

$$D = \frac{2n\lambda L}{d} \, . \tag{4}$$

But from de Broglie hypothesis, de Broglie wavelength of an electron accelerated through a potential V is:

$$\lambda = \frac{h}{\sqrt{2meV}} \, . \tag{5}$$

Thus, from (4) and (5),

$$D\sqrt{V} = \frac{nhL}{d}\sqrt{\frac{2}{me}} \, . \tag{6}$$

Since all the quantities on the right-hand side are constant, for a set of atomic planes, i.e., for constant d, the product $D\sqrt{V}$ must be a constant if de Broglie waves exist for electrons.

In the experiment, electrons were accelerated through various potentials and the diameter of the ring in the diffraction pattern was measured for aluminum and gold thin films. For both films, the product $D\sqrt{V}$ was found to be constant, which confirmed the de Broglie hypothesis.

Suggested Reading

[1] K Krane, *Modern Physics*, John Wiley & sons Pvt. Ltd., Singapore, pp.70–75, 1996.

[2] G P Thomson, Experiments on the Diffraction of Cathode Rays, *Proceedings of Royal Society of London. Series A*, Vol.117, pp.600–609, 1928.