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Review Article

# Davission-Germer's Experiment and Wave Nature of Electron: A Brief Review

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***Abstract***— The main purpose of the review article is to introduce the Davission–Germer experiment, to prove the wave nature of electrons through the electron diffraction technique. Initially, de-Broglie proposed a theory about the wave nature of the particle. He argued that every particle has a wave character like each wave has a particle character. He made a valid point by saying due to the law of symmetry of nature if the wave has particle nature, then there must be the particle having wave character. Many scientists tried to prove the above statement true but failed. It is the 1st experiment evidence of the wave nature of the particle. In the experiment, it is proved that an electron (particle) has a wavelength which means the electron has a wave character. If it is true, we can say that radiation has a dual nature i.e., wave and particle. Special attention has been given to the experimental set-up, especially, the scattering of electrons from the nickel crystal, the position of the electron detector, mathematical calculation, and graphical interpretation.

***Keywords***— Davission–Germer experiment; de-Broglie; electron diffraction technique; nickel crystal; electron detector; graphical interpretation

## 1. Introduction

In 1921, Albert Einstein won the Nobel Prize for photoelectric effect. As a particle, a photon (light) carries energy that is proportional to the frequency of the wave and the interaction of the photons and electrons (if a photon has sufficient frequency) produces a photoelectric effect i.e. he proved the radiation has particle character [1-2]. After that many physicists raised the question that there must be an analogy theory to the photoelectric effect i.e. every particle has a wave character. In 1924, French physicist Louis Victor de-Broglie argued that nature was symmetrical. Due to the law of symmetry, the two basic physical entities matter and energy must have symmetrical character i.e. the moving particle of matter should display wave-like properties [3-4]. The wavelength of the associated particle is called the de-Broglie wavelength. However, there was no experimental confirmation of the de-Broglie hypothesis. In 1927, two American physicists Davission and Germer gave the first experimental evidence of matter waves [5-7].

According to Planck's theory, energy radiates from the material in a discrete manner instead of continuous. So, the energy emitted from a black body is directly proportional to the frequency. Interestingly, only a discrete amount of energy (one quantum) can radiate i.e., integral multiple of hν, where ν is the frequency of the radiated energy wave and h = Planck's constant = 6.62 x $10^{-34}$ J.s

So, the energy of one quantum can be written as;

$$E = h\nu \quad \ldots\ldots\ldots\ldots (1)$$

According to Einstein's mass-energy relation,

$$E = mc^2 \quad \ldots\ldots\ldots (2)$$

From eqs. (1) and (2), we get

$$mc^2 = h\nu$$

$$mc^2 = h\frac{c}{\lambda}$$

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

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

According to the de-Broglie equation,

$$\lambda = \frac{h}{P} = h/\sqrt{2mE} = h/\sqrt{2meV}$$

Where, m = the mass of an electron, a e = charge of an electron, and V= potential difference

We can generalize this for any material particle with non-zero rest mass. Each material particle of momentum 'p' behaves as a group of waves (matter waves) whose wavelength and wave vector 'k' are governed by the speed and mass of the particle. This is a well-known topic in quantum mechanics, but authors have taken a step to explain it with easy language and make it more interesting to a large section of the reader particularly B.Sc. & M. Sc students.

## 2. Experimental Details

The verify the wave nature of the electron, Davission-Germer set up an experimental base as shown in Figure 1. A lowering of the value of pressure means the creation of a high vacuum system. In the 1st step, a vacuum pressure of 3 mbar was maintained inside the chamber in the experimental setup. The main purpose of the vacuum system is to avoid inelastic scattering of the diffracted electrons during the experiment.

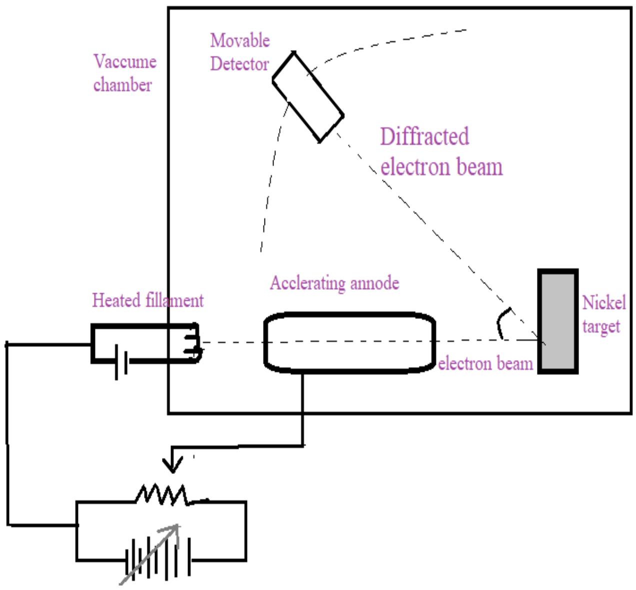



Figure 1: Division-Germer experimental set-up

In 2nd step, a low-tension battery (LTB) was connected to the tungsten filament having a high melting point of 3380 ºC. The main purpose of connecting tungsten filaments is to produce high-energy electrons through thermionic emission using Joule’s heating effect. In 3rd step, an opposite charge plate i.e., an accelerating anode plate maintained at a potential of V, was kept in the path of the emitted electrons. Therefore, the connected accelerating positive plate is called a particle accelerator. The accelerator is housed within a cylinder in which electrons are running along its axis with a restricted path with the help of a collimator. The main purpose of a collimator is to prepare a narrow and straight (collimated) electron beam ready to hit the target. In 4th step, these electron beams fall on a large single crystal of nickel. As the nickel target is polycrystalline, thus electrons emit a smooth angular distribution in almost every direction, which can be carefully captured. The crystal is positioned in such a way that it may be rotated around a fixed axis. In 6th step, a detector is used to collect dispersed electrons from the nickel crystal. The electrons are scattered in all directions by the atoms in the crystal. The detector can be moved to any angle θ reflective of the incident beam. A movable Faraday cup electron detector was used to count the number of electrons scattered at various angles.

The energy of electrons in the primary beam, the angle at which they reach the target, and the position of the detector could all be varied. The detector used here can only identify the presence of an electron in the form of a particle. Consequently, electrons are received by the detector in the form of an electrical current. Experiments are being conducted on the scattering angle and the intensity (strength) of the electrical current received by the detector. This electron intensity is referred to as current.

The intensity of the scattered electrons varies with accelerating voltage. It shows the highest and lowest values that match the X-ray diffraction pattern's maxima and minima.

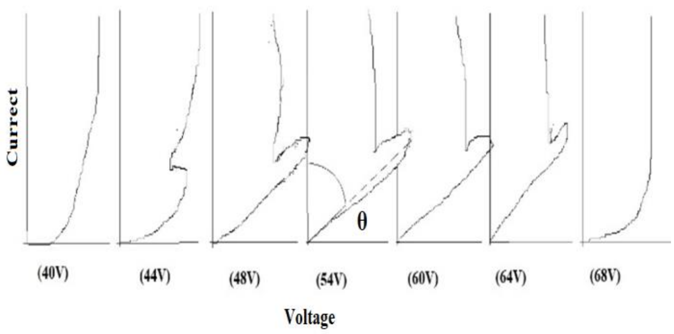



Figure 2: Variation of current versus accelerating voltage

We were able to alter the scattered electrons' intensity (I) by adjusting the scattering angle (θ). Through adjustment of the accelerating potential difference, the accelerated voltage was varied from 44V to 68V as shown in Figure 2. At 50° scattering angle, we were able to identify a notable peak in the intensity (I) of the scattered electron with an accelerating voltage of 54 V. The constructive interference of electrons scattered from different layers of the uniformly spaced atoms in the Ni crystal will have a fixed phase difference produced at this peak. The whole experimental setup is fully computerized. These waves will interact either constructively or destructively after reflection and the diffraction pattern of an electron is the outcome as seen by a computer.

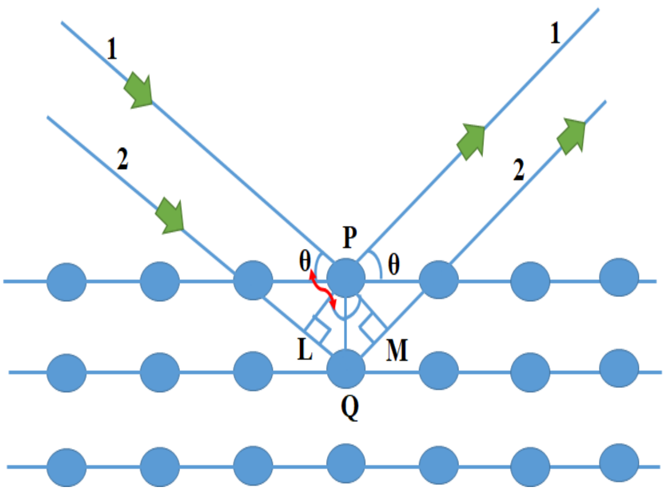
## 3. Result and Discussion

There are a few unsolved problems in physics, which could not be solved by taking the concept of classical mechanics. As per the classical theory, energy is a continuous beam of light and attains maximum value when the amplitude of the wave is maximum. Therefore, the stability of the atom, black body radiation, Compton's effect, and pair production could not be explained using the classical electromagnetic theory [8-11]. Many scientists have tried to develop a theory that can explain the above-mentioned problems. But finally, Planck could successfully explain the black body radiation by introducing of concept of energy discrete nature. The energy radiated from the black body is an integral multiple of $h\nu$, where $\nu$ is the frequency of the radiated wave. The radiated energy was carried by the photons. The energy of the single photon is $h\nu$. Then, Einstein derived the equation of the photoelectric effect by taking photons are massless particles and moving with the speed of light. When photons are moving in space, they have wave character. But, when they interact with matter, they show their particle nature. So, as per Einstein's radiation-matter interaction theory, each wave has a particle nature.

It is well-known that nature has a symmetry character. Taking the concept of the law of symmetry, de-Broglie argued that why not every particle has a wave character. He said that every particle is associated with a certain wavelength, called as de-Broglie wavelength.
We can calculate the wavelength of the electron by using de-Broglie's equation $\lambda = h/\sqrt{2meV}$
Here, $h = 6.62 \times 10^{-34}$ J.s, V = 54 volts, m = $9.1 \times 10^{-31}$ kg and $e = 1.6 \times 10^{-19}$ C
Now,
$\lambda = 6.62 \times 10^{-34}/\sqrt{2 \times 9.1 \times 10^{-31} \times 1.6 \times 10^{-19} \times 54}$ = 0.167 $nm$ …… (1)
Therefore, the wavelength of the electron is 0.167 $nm$.

This experimental result should be supported by the theoretical model. In the present context, Bragg's law of diffraction was used to verify the wave nature of the electron by taking the theoretical concept. X-ray diffraction is based on the fundamental principle of constructive interference between the monochromatic X-rays and the respective sample. Cathode ray tubes are urged to generate X-rays through a thermionic process which is often filtered out to liberate the monochromatic beam of radiation λ. These radiations are hence collimated to concentrate and focused on the mounted sample by an incident/glancing angle θ. In this process, incident rays interact with the mounted sample to produce constructive interference. The diffraction pattern is the result of the constructive interference of these reflected rays from the nickel crystal plane. Again, to have constructive interference the path difference between the rays (ray 1 and ray 2) must be an integral multiple of wavelength λ and satisfy Bragg's law as shown in Figure 3.

**Figure 3 shows Bragg's reflection observed from X-rays from the nickel atomic plane**




Bragg's law provides the relation between the interplanar spacing and diffraction angle with that of the wavelength of electromagnetic radiations. The path difference (Δ) between rays 1 and 2 is (LQ + QM). In ΔPQL, $\sin\theta$ = LQ/PQ
Or, LQ = PQ sinθ = dsinθ
Similarly, In ΔPQM, $\sin\theta$ = QM/PQ
Or, QM = PQ sinθ = dsinθ
Therefore, the net path difference between ray 1 and 2 = LQ+QM = dsinθ+ dsinθ = 2 dsinθ
To observe the maxima in the diffraction, pattern the path difference should be equal to $n\lambda$
Therefore, 2dsinθ = nλ …………….. (2)

where, d = interplanar spacing of the planes, θ = angle between the incident rays and the crystal plane known to be the glancing angle, n = order of reflection, and λ = wavelength of incident beam [12-14]. The geometry of incident X-rays caromed with the mounted nickel specimen when satisfies the Bragg relation, constructive interference takes place and results in intensified peaks. The intensity of the reflected lines reduces with the increase in the value of n or θ, where sinθ ≤ 1 as well as λ ≤ d to satisfy Bragg's reflection.
Here, d = 0.91 nm, $\theta = 90^0 - 50^0/2 = 65^0$ and n = 1 ($1^{st}$ order maximum)
2dsinθ = nλ
Or, $2 \times 0.91 \times 10^{-9} \times \sin 65^0 = 1 \times \lambda$
Or, λ=0.165 $nm$ ………………… (3)

Now, comparing the results from both the Davission-Gerner experiment [from eq.(2)] and Bragg's law of diffraction [from eq.(3)], it can be concluded that the electron has a wavelength of nearly 0.165 nm. Therefore, finally, it can be concluded that each particle is associated with wave character.

## 4. Conclusion and Future Scope

In this section, we want to discuss how the wavelength of the electron was calculated and another theoretical model strongly supports the results. From the beginning, the father of quantum mechanics Max Planck proposed that the energy radiated from the black body in a discrete nature and integral multiple of the frequency with Planck's constant. Later, Einstein proved that every wave has particle character taking the concept of radiation interacting with matter. Then, de-Broglie said that every particle must have wave character according to the law of symmetry of nature. In this direction, both scientists Davission & Germer set up an experiment and verified the wave nature of the electron. From the experiment, they calculate the wavelength of the electron is about 0.167 nm while from the theoretical model, the wavelength of the electron is found to be 0.165 nm. Since both results are very close to each other, we can conclude that the electron has wavelength. So, the wave nature of the electricity is verified,

**Data Availability**
Data will made available on reasonable request.

**Conflict of Interest**
There is no conflict of interest to declare

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**Itina Upasana**: Writing- Original Draft, Conceptualization & Methodology**, S.K Parida**: writing- Reviewing & Editing, Visualization & Supervision

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