Davisson and Germer Experiment by Dr. Sushil Kumar

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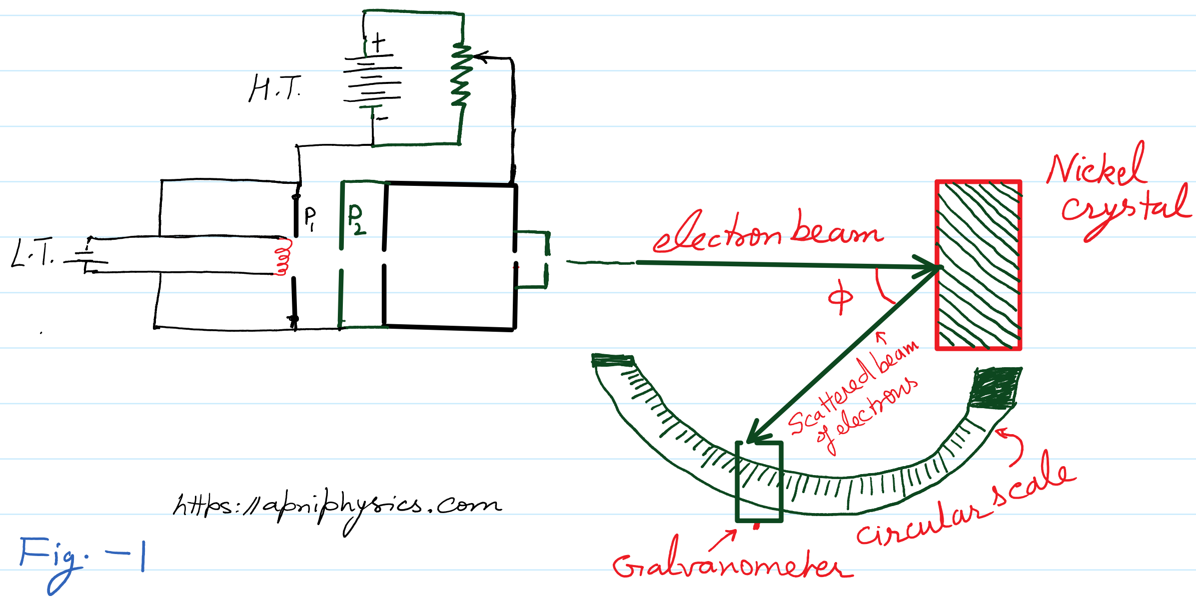


Fig. -1

The purpose of the Davisson and Germer Experiment was to demonstrate that matter exhibits dual nature, both wave-like and particle-like.

Don't confuse in starting with 'matter', taking it means like big stone, heavy metal iron pieces, gold, sand or water, etc. No doubt, these are, but my concern is with "Electrons" here, a tiny particle of the atom. Its have mass, no matter how much that small is 9.1×10^{-31}Kg, after all it is considered as a materialistic particle.

So, point is, you are aware that how we have to understand Davisson and Germer experiment in this perspective of matter (an electron).

Introduction to Davisson and Germer Experiment

This story is from the early 20th century when modern physics was developing. Many physicists were transitioning to the field of modern physics from disciplines such as electricity-magnetism, optics, and thermodynamics to quantum physics. As you may know, in 1924, de Broglie introduced a bold hypothesis in his Ph.D. dissertation, suggesting that matter also exhibits a dual nature, similar to radiation. Consequently, famous scientists of that time, including Einstein, Schrödinger, Planck, Dirac, Jordan, and others, were attempting to comprehend the quantum world.

As part of this progression, in 1927, Davisson and Germer demonstrated that a beam of electrons exhibits diffraction phenomena (interference and diffraction phenomena are only possible with waves). They employed an apparatus equipped with a heated filament for electron emission, a nickel crystal, and a galvanometer

Davisson and Germer Experiment Arrangement

Essential parts of this apparatus are;

1. Electron Gun
2. The Target; nickel crystal
3. and the Farady box collector

The electrons emits with different kinetic energy from cathode. They are accelerated by electric field and projected on to the nickel crystal. The electrons are scattered in all possible directions by the atoms in the crystal. In next paragraph, it is shown and explained with the help of lattice (lattice is an array of atoms which is defined in a systematic order for each crystal).

The Intensity of the scattered electrons are measured by the collector. Electrons enter through a window where a Galvanometer is connected with it, this arrangement can moved on a circular scale. The angle between the axis of the incident beam and the line joining the collector with target, can be varied from 20^0 to 90^0 degrees.

Davisson and Germer Experiment Explanation

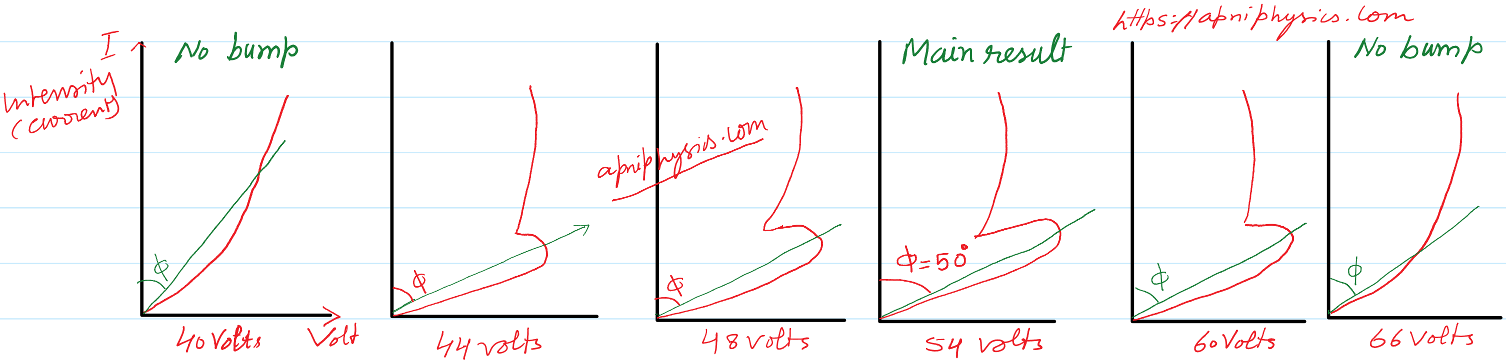
There are two types of electrons one that is coming from electron gun and second from the crystal target. The speed of these electrons (coming from target) are less than the speed of incident electrons. So, these slow electrons are excluded from the collector by using the retarding potential approach.

Normal incidence of the electrons beam

In this case, beam of electrons is allowed to fall normally on the surface of nickel crystal. As a result, electrons are scattered in all the directions by the atoms in the crystal. At the beginning, electrons are projected at a small voltage V, and the crystal was allowed to place at any arbitrary azimuth. The collector which includes Galvanometer can be slide on the circular scale to detect the scattered electrons, through a window.

At each position galvanometer current is noted, it was a measure of the intensity of diffracted beam. Further, a graph is plotted between the co-latitude and galvanometer current. Co-latitude is the angle between the incident beam and the line connects the window of collector to the target.

At different voltages, both currents and co-latitude were measured and then plotted as shown in the figure below.



In this process, it is observed that a bump begins to appear in the curve, at 44 volt. With increasing the potential the bump started to increase. At a certain value of the voltage i.e., V= 54 Volts and co-latitude $\phi = 50^0$, it reaches to its maximum stage. After it increasing the value of voltages, it starts to decreases gradually and disappear above voltage $V \cong 66$ Volts.

Interpretation of Bump in Davisson and Germer Experiment

The biggest bump signifies the state of electrons wave nature. Let understand it by the de-Broglie' matter waves concept and the Braggs diffraction concept. For it, we have to check the results of both these concepts using experimental data observed in this experiment, for a specific situation.

(a). According to the de-Broglie wave theory of matter, the formula for wavelength of electrons accelerated at a potential V is;

$$\lambda = \frac{12.27}{\sqrt{V}} A^\circ$$

The voltage V = 54 V at the most prominent bump time. So the associated wavelength of the electron particle will be;

$$\lambda = \frac{12.27}{\sqrt{54}} A^\circ = \frac{12.27}{7.348} \qquad (\sqrt{54} = 7.348)$$

$$\lambda = \frac{12.27}{7.348} A^\circ = 1.67 A^\circ$$

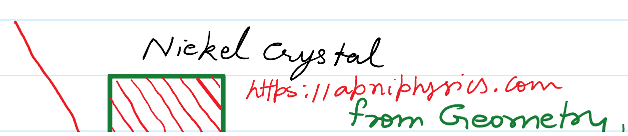
This is the wavelength of matter waves associated with the particle electron.

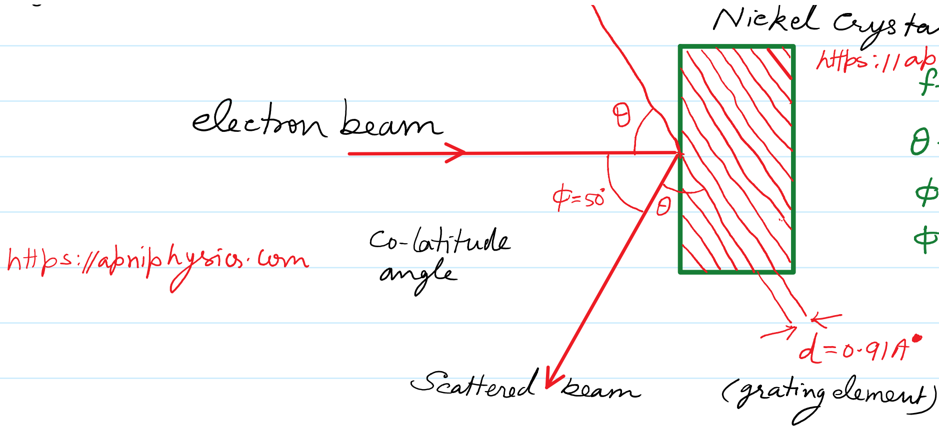
(b). Now the second part which is based on the Braggs diffraction. We know that nickel crystal acts as a plane diffraction grating having grating element d = 0.91 A^0. As per the observations, most prominent bump was observed at 54 Volts and at co-latitude $\phi = 50^o$.
From Braggs' diffraction law,

$$n\lambda = 2d\sin\theta,$$

here θ is unknown to us, so how to find it? For it we will consider the nickel crystal and electrons beam geometry. Below in this figure you can see θ, so ;

Figure





from Geometry,

$$\theta + \phi + \theta = 180^\circ$$

$$\phi + 2\theta = 180^\circ \Rightarrow 2\theta = 180 - \phi$$

$$\phi = 50^\circ, \quad \theta = \frac{180-50}{2} = \frac{130}{2} = 65^\circ$$

$$\boxed{\theta = 65^\circ}$$

So, for n=1 ;

$$n\lambda = 2d\sin\theta,$$

$$\lambda = 2d\sin 65^\circ$$

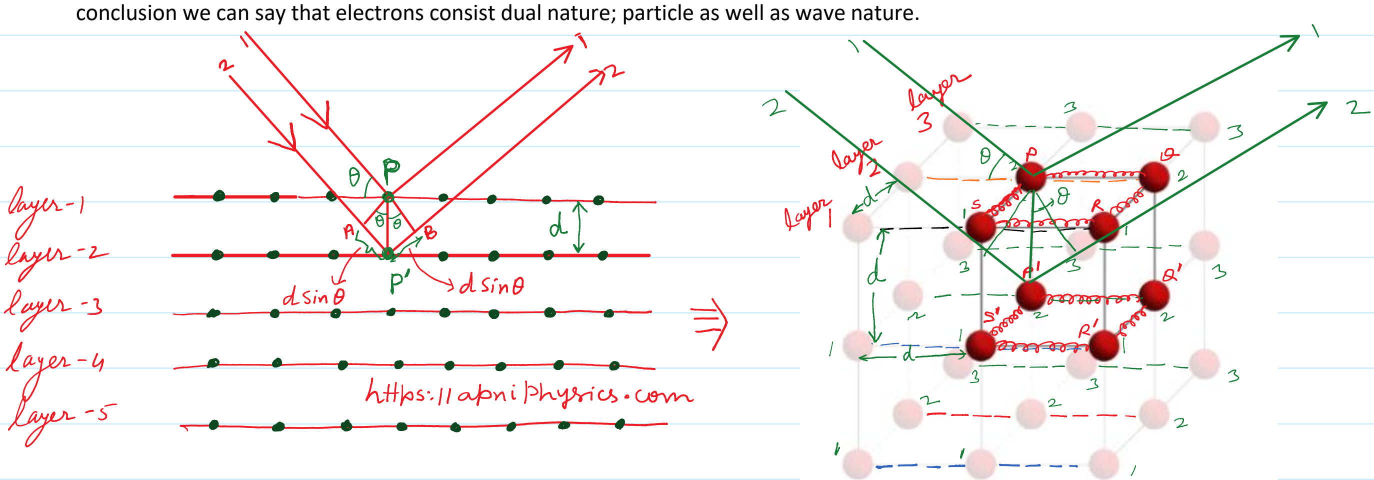
$\sin 65^0 = 0.906$

$d = 0.91\ A^0$

$$\lambda = 2 \times 0.91 \times 0.906\ A^\circ = 2 \times 0.82446\ A^\circ$$

$$\lambda = 1.65\ A^\circ$$

This result is in agreement with the de-Broglie's wavelength. It confirms that electrons shows the dual nature behavior. In conclusion we can say that electrons consist dual nature; particle as well as wave nature.



From Braggs' diffraction law,

There are two waves (in phase from the origin), wave 1 scattered from the point P i.e., an atom's position in the lattice. Keeping in mind the concept of the wave-front, the second wave, which was in the same phase reaches at the P' point few times later i.e., an atom's position into inner sider layer of the atoms.

Both these points are lattice points which you can see from right hand side. Now, there will be path differences between these two diffracted rays, which is;

$d \sin\theta + d \sin\theta = 2d \sin\theta$

These two waves now superimpose and as a result will construct, a constructive and destructive interference. For the constructive interference there will be maxima which satisfies the condition;

$n\lambda = 2d \sin\theta$

so by this way, Davisson and Germer, noted the observation keeping crystal with some orientation. Here angle θ, represents to that orientation of the crystal.

$$n\lambda = 2d\sin\theta$$

$n\lambda = 2d \sin\theta$

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NOTE:

1. Photoelectric effect experiment was in favor of the particle nature, while
2. Interference and diffraction phenomenon are in favor of the wave nature.

Electron shows both the characteristics, that is why we says it's have dual nature.

FACT: You know all particles can not show the dual nature, an important point is here, actually if the size of any particle is comparable to their de Broglie wavelength, only then it shows dual nature. You can apply the same on any materialistic particles.
Frequently Asked Questions:
What is lattice?
What are Braggs planes?
What is diffraction?
How bump represents the diffraction?

FREQUENTLY ASKED QUESTIONS:

1.Question: What is lattice?

Answer: A crystal lattice, also known as a crystal structure, is a three-dimensional arrangement of atoms, ions, or molecules in a crystalline solid. This arrangement is highly ordered and repetitive, which gives crystals their characteristic structure and properties.

2. Question: What are Braggs planes?

Answer: Bragg's planes, often referred to as Bragg planes or Bragg reflections, are a concept in the field of X-ray crystallography and the study of crystal structures. They are named after the English physicists Sir William Henry Bragg and his son Sir William Lawrence Bragg, who made significant contributions to this field and formulated Bragg's Law. Bragg's Law describes the relationship between the angles at which X-rays are diffracted by a crystal lattice and the wavelength of the X-rays, as well as the spacing between the crystal lattice planes. The law can be expressed as:
$n\lambda = 2d \times \sin(\theta)$

3. Question: What is diffraction?

Answer: Diffraction is a phenomenon in physics that occurs when waves encounter an obstacle or a slit and bend around it, spreading out and creating a pattern of interference. This phenomenon is most commonly associated with waves of light, sound, or water, but it can also apply to other types of waves, including X-rays, electrons, and more. Diffraction patterns provide valuable information about the properties of waves and the structures they interact with.

4. Question: How bump represents the diffraction?

Answer: In the Davisson and Germer experiment, a beam of electrons was directed at a crystalline nickel target. The electrons were accelerated and had a significant amount of energy. When the high-energy electrons struck the crystal lattice of the nickel target, they interacted with the regularly spaced atoms in the lattice. This interaction resulted in the scattering of the electrons.

As the electrons were scattered by the atoms in the crystal lattice, they formed a diffraction pattern on a detector screen placed behind the crystal. This pattern consisted of bright and dark regions. The bump or peak in the diffraction pattern represents the central maximum or the central bright spot in the pattern. This central maximum is where the scattered electrons interfere constructively, meaning that the waves of the scattered electrons reinforce each other. It is the most intense part of the diffraction pattern.

From <https://apniphysics.com/science/davisson-germer-experiment-2/>