Particle properties of wave: Matter Waves

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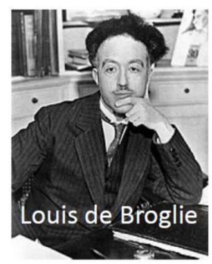
Matter Waves

The wave nature associated with the material particle is known as matter waves.

- You know about the Compton Effect, it proofs the particle nature of wave.
- Can a particle have also wave nature?
- Nature like symmetry!

Macroscopic object

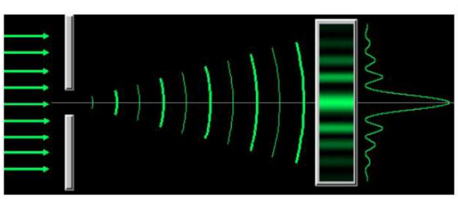
Microscopic object

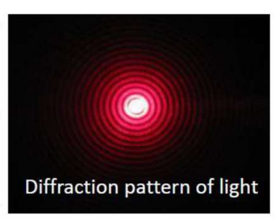


Louis de Broglie

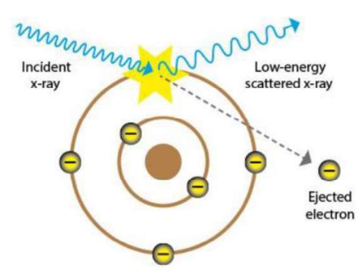
Dual nature of EM radiation: Wave and particle nature

- Electromagnetic radiation behaves like waves and propagates according to Maxwell's Equations.
- Wave like nature of EM radiation was confirmed in experiments like interference and diffraction.
- Particle like nature of EM radiation was confirmed by Compton scattering and Photoelectric effect.





Diffraction pattern of light



Compton Scattering

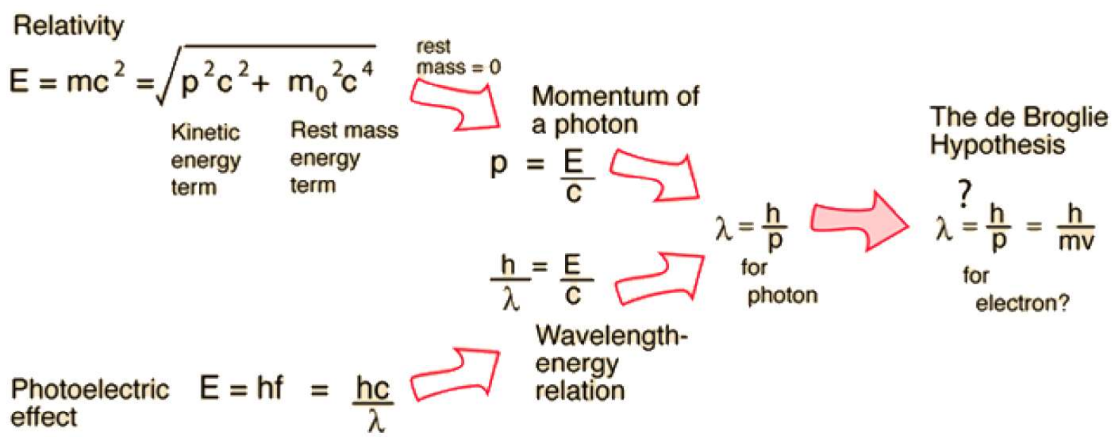
Particle Properties	Wave Properties
Mass (m)	Frequency (ν)
Velocity (v)	Wavelength (λ)
Momentum (p)	Amplitude (A)
Energy (E)	Intensity (I)

De Broglie's Hypothesis

- Louis Victor de Broglie in 1923 in his doctoral dissertation postulated that "because photons have wave and particle characteristics, perhaps all forms of matter have wave as well as particle properties".
- This was a radical idea with no experimental confirmation at that time.
- According to de Broglie, electrons had a dual particle–wave nature.
- Accompanying every electron was a wave (not an electromagnetic wave!), which guided, or "piloted," the electron through space.
- This gave him a Nobel Prize in Physics in 1929 (just one year after Sir CV Raman got Nobel).

De Broglie's Wavelength

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

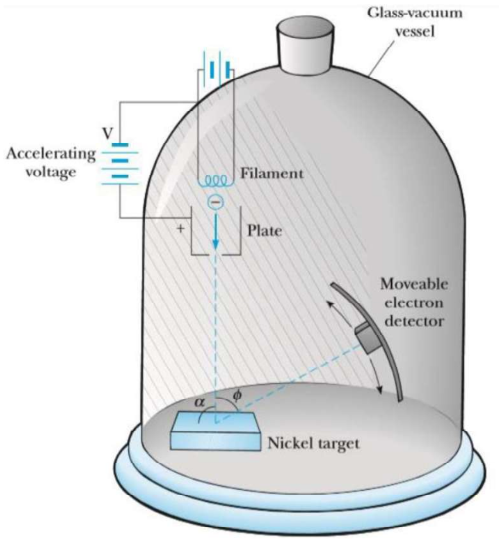


Davisson-Germer Experiment

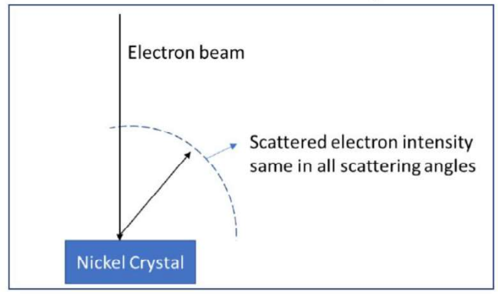
- Davisson and Germer demonstrated the wave nature of electron by their experiment.
- They set out to study the surface of metals, in particular, nickel. They intended to do that by scattering electrons from the surface of nickel and observing the scattered electron.
- A collimated beam of electron is produced is using the electron gun and made to incident on a target of nickel crystal. The electrons are scattered in all direction by the atomic planes of nickel crystal.
- The intensity of the scattered electrons is measured by an electron detector. This detector can be moved in a circular direction and the scattered electron intensity is studied at different angles.

Davisson-Germer Experiment: proves the existence of matter waves

Wave nature of electrons



Classical Theory



Davisson-Germer Experiment

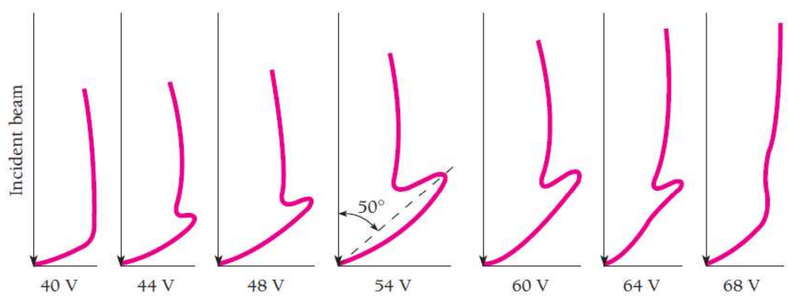
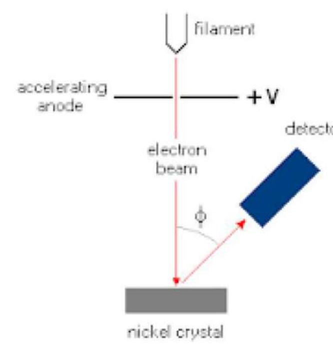
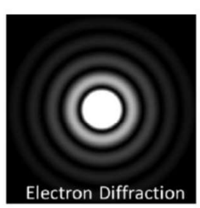


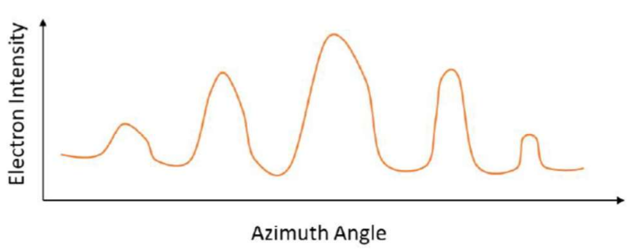
Figure 3.7 Results of the Davisson-Germer experiment, showing how the number of scattered electrons varied with the angle between the incoming beam and the crystal surface. The Bragg planes of atoms in the crystal were not parallel to the crystal surface, so the angles of incidence and scattering relative to one family of these planes were both 65° (see Fig. 3.8).



Davisson-Germer Experiment

Experimental Observation





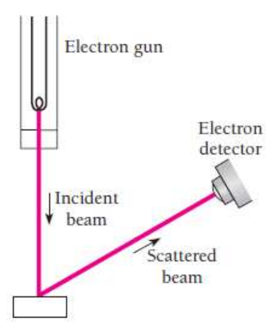


Figure 3.6 The Davisson-Germer experiment.

Observations of Davisson Germer experiment:

From this experiment, we can derive the below observations:

- We obtained the variation of the intensity (I) of the scattered electrons by changing the angle of scattering θ.
- By changing the accelerating potential difference, the accelerated voltage was varied from 44V to 68V.
- With the intensity (I) of the scattered electron for an accelerating voltage of 54V at a scattering angle θ = 50º, we could see a strong peak in the intensity.
- This peak was the result of constructive interference of the electrons scattered from different layers of the regularly spaced atoms of the crystals.
- With the help of electron diffraction, the wavelength of matter waves was calculated to be 0.165 nm.

Using Bragg's diffraction Law:

$$2d\sin\theta = n\lambda$$
$$n = 1$$
$$\theta = 65^o$$
$$d = 0.91A^\circ$$
$$\Rightarrow \lambda = 1.66A^\circ$$

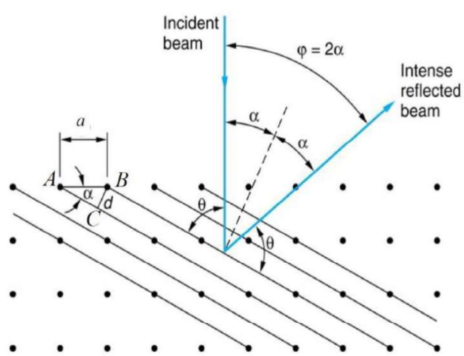


Figure (3) Bragg reflection

$$\sin\alpha = \frac{BC}{AB} = \frac{d}{a}$$
$$a = 2.15A^\circ$$
$$\alpha = \frac{\phi}{2} = \frac{50^\circ}{2} = 25^\circ$$
$$\therefore d = 0.91A^\circ$$

Using de Broglie's wavelength:

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$$
$$m = 9.1\times10^{-31}kg$$
$$e = 1.6\times10^{-19}C$$
$$V = 54V$$
$$\Rightarrow \lambda = 1.67A^\circ$$

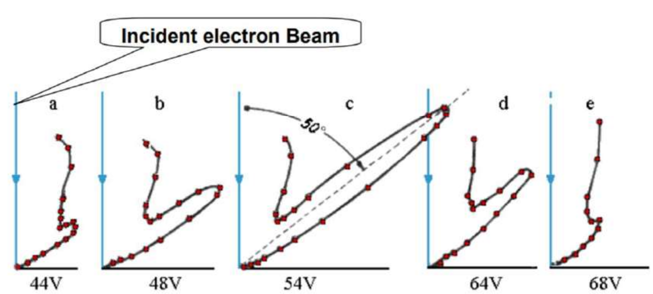


Figure (2) Diffraction of electron beam at different applied voltage

Wavelength of the electron determined using de Broglie's wavelength and Bragg's diffraction law agree well: This proves the existence of matter waves

Properties of Matter waves

1. Only generated by moving particle. If the velocity v → ∞, the wavelength will be zero and vice versa if v = 0, λ → ∞ is the wave becomes indeterminate. This shows that matter waves are generated by the motion of particles.
2. Independent of charge of the particle. Matter waves are produced by the charged or uncharged particles.
3. The velocity of the matter wave depends on the velocity of a matter particle i.e., it is not a constant, while the velocity of the EM wave is a constant.
4. The lighter the particle, the grater is the wavelength associated with it, because λ ∝ 1/m.
5. Larger the velocity of the particle, smaller is the wavelength associated with the particle, because λ ∝ 1/v.
6. The velocity of a matter wave is greater than the velocity of light.

Matter Waves/DeBroglie waves: $\lambda = \frac{h}{p} = \frac{h}{mv}$

$\lambda = 10^{-34}$m

Tiny wavelength-can be ignored

Submicron Objects

e^-

$\lambda = 10^{-10}$m= 1Å

Comparable with atomic length scale

Electrons are considered as both waves and particles

What is the wave nature of electrons??

In general, whenever the de Broglie wavelength of an object is in in the range of its size, the wave nature of the object is detectable