UNIT 8
DUAL NATURE OF RADIATION AND MATTER

Warm greetings:

Dear students

Welcome all. In this section we learnt about matter waves. Now we are going to discuss about

- Matter waves
- De broglie wave
- Electron microscope

MATTER WAVES:

Introduction - Wave nature of particles:

- So far, we learnt that the characteristics of particles and waves are different.
- A wave is specified by its frequency, wavelength, wave velocity, amplitude and intensity.
- It spreads out and occupies a relatively large region of space. A particle specified by its mass, velocity, momentum and energy occupies a definite position in space and is very small in size.
- Classical physics treated particles and waves as distinct entities. But quantum theory suggested dual character for radiations – that is, radiation behaves as a wave at times and as a particle at other times.
- From this wave – particle duality of radiation, the concept of wave nature of matter arises which we will see in this section.

De Broglie wave:

The wave–particle duality of radiation was extended to matter by a French physicist Louis de Broglie (pronounced as de Broy) in 1924.

Greatly influenced by the symmetry in nature, de Broglie suggested that if radiation like light can act as particles at times, then material particles like electrons can also act as waves at times.

According to de Broglie hypothesis, all material particles like electrons, protons, neutrons in motion are associated with waves. These waves are called de Broglie waves or matter waves.

De Broglie wave length:

The momentum of photon of frequency *v* is given by

$$p = hv/\ c = h/\lambda \qquad \text{since} \quad c = \upsilon\lambda$$

The wavelength of a photon in terms ofits momentum is

$$\lambda = \frac{h}{p} \qquad (8.9)$$

This wavelength of the matter waves is known as **de Broglie wavelength**. This equation relates the wave character (the wave length λ) and the particle character (the momentum *p*) through Planck's constant.

De Broglie wave length of electrons:

Let an electron of mass *m* be accelerated through a potential difference of *V* volt. The kinetic energy acquired by the electron is given by

$$\frac{1}{2}m\upsilon^2 = eV$$

Therefore, the speed υ of the electron is

$$\upsilon = \sqrt{\frac{2eV}{m}} \qquad (8.11)$$

Hence, the de Broglie wavelength of the matter waves associated with electron is

$$\lambda = \frac{h}{m\upsilon} = \frac{h}{\sqrt{2emV}} \qquad (8.12)$$

Substituting the known values in the above equation, we get

$$\lambda = \frac{6.626\times10^{-34}}{\sqrt{2V\times1.6\times10^{-19}\times9.11\times10^{-31}}}$$

$$= \frac{12.27\times10^{-10}}{\sqrt{V}}\,\text{m} \quad \text{(or)}$$

$$\lambda = \frac{12.27}{\sqrt{V}}\,\text{Å}$$

For example, if an electron is accelerated through a potential difference of 100V, then its de Broglie wavelength is 1.227 Å.

Since the kinetic energy of the electron, $K = eV$, then the de Broglie wavelength associated with electron can be also written as

$$\lambda = \frac{h}{\sqrt{2mK}} \quad (8.13)$$

Davisson – Germer experiment:

- Louis de Broglie hypothesis of matter waves was experimentally confirmed by Clinton Davisson and Lester Germer in 1927.
- They demonstrated that electron beams are diffracted when they fall on crystalline solids.
- Since crystal can act as a three-dimensional diffraction grating for matter waves, the electron waves incident on crystals are diffracted off in certain specific directions.
- Figure 8.17 shows a schematic representation of the apparatus for the experiment.
- The filament *F* is heated by a low tension (L.T.) battery.
- Electrons are emitted from the hot filament by thermionic emission.
- They are then accelerated due to the potential difference between the filament and the anode aluminium cylinder by a high tension (H.T.) battery.
- Electron beam is collimated by using two thin aluminium diaphragms and is allowed to strike a single crystal of Nickel.

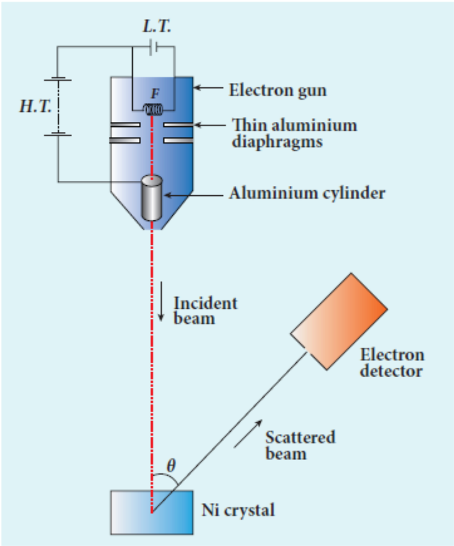


Figure 8.17 Experimental set up of Davisson – Germer experiment

- The electrons scattered by Ni atoms in different directions are received by the electron detector which measures the intensity of scattered electron beam.
- The detector is capable of rotation in the plane of the paper so that the angle θ between the incident beam and the scattered beam can be changed at our will.
- The intensity of the scattered electron beam is measured as a function of the angle θ.

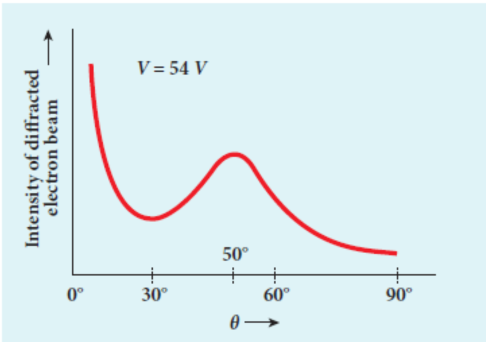


Figure 8.18 Variation of intensity of diffracted electron beam with the angle θ

Figure 8.18 shows the variation of intensity of the scattered electrons with the angle θ for the accelerating voltage of 54*V*. For a given accelerating voltage *V*, the scattered wave shows a peak or maximum at an angle of 50° to the incident electron beam.

This peak in intensity is attributed to the constructive interference of electrons diffracted from various atomic layers of the target material.

From the known value of interplanar spacing of Nickel, the wavelength of the electron wave was experimentally calculated as 1.65Å.The wavelength can also be calculated from de Broglie relation for *V* = 54 V from equation (8.18).

$$\lambda = \frac{12.27}{\sqrt{V}} \text{Å} = \frac{12.27}{\sqrt{54}} \text{Å}$$

$$\lambda = 1.67 \text{ Å}$$

This value agrees very well with the experimentally observed wavelength of 1.65Å. Thus this experiment directly verifies de Broglie's hypothesis of the wave nature of moving particles.

Electron Microscope:

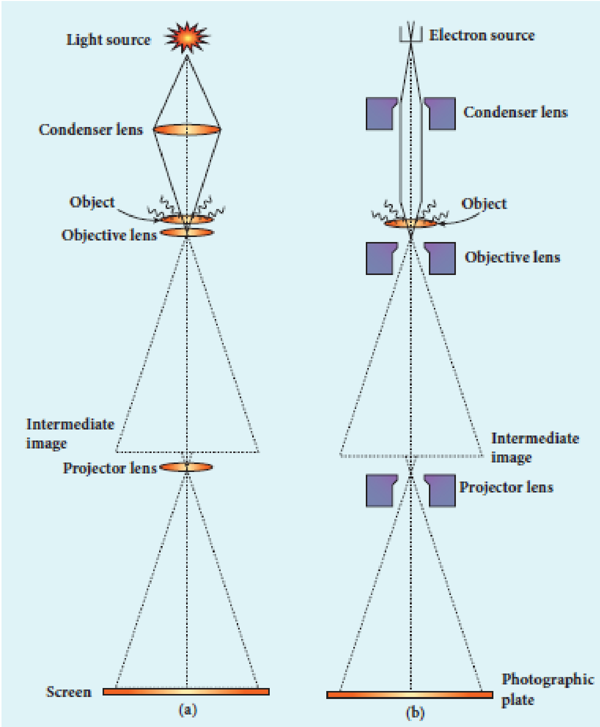
Principle:

This is the direct application of wave nature of particles. The wave nature of the electron is used in the construction of microscope called **electron microscope**.

- The resolving power of a microscope is inversely proportional to the wavelength of the radiation used for illuminating the object under study.
- Higher magnification as well as higher resolving power can be obtained by employing the waves of shorter wavelengths.
- Louis de Broglie wavelength of electron is very much less than (a few thousands less) that of the visible light being used in optical microscopes.
- As a result, the microscopes employing de Broglie waves of electrons have very much higher resolving power than optical microscope.
- Electron microscopes giving magnification more than 2,00,000 times are common in research laboratories.

Working:

- The construction and working of an electron microscope is similar to that of an optical microscope except that in electron microscope focussing of electron beam is done by the electrostatic or magnetic lenses.
- The electron beam passing across a suitably arranged either electric or magnetic fields undergoes divergence or convergence thereby focussing of the beam is done (Figure 8.19).
- The electrons emitted from the source are accelerated by high potentials. The beam is made parallel by magnetic condenser lens.
- When the beam passes through the sample whose magnified image is needed, the beam carries the image of the sample.
- With the help of magnetic objective lens and magnetic projector lens system, themagnified image is obtained on the screen.
- These electron microscopes are being used in almost all branches of science.


Light source
Condenser lens
Object
Objective lens
Intermediate image
Projector lens
Screen
(a)
Electron source
Condenser lens
Object
Objective lens
Intermediate image
Projector lens
Photographic plate
(b)

@@@@@@@