Application of Dual Nature of Matter

Objectives

After going through this module the learner will be able to :

- Know the application of dual nature of matter and waves
    - Photoelectric cells
    - Light dependant resistance
    - Electron microscope

Content Outline

- Unit syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Application of dual nature of matter
    - Photoelectric effect
    - Light dependant resistance
    - Electron microscope
- Summary

Unit Syllabus

Unit 7

Dual Nature of Radiation and matter

Dual nature of radiation, photoelectric effect, Hertz and Lenard's observations, Einstein's photoelectric equation, particle nature of light

Matter waves, wave particle duality, nature of particles de Broglie relation, Davisson -Germer experiment (experimental details should be omitted only conclusion should be explained)

Module Wise Distribution Of Unit Syllabus - 5 Modules

Module 1	• Introduction • Electron emission • Photoelectric effect

	• Hertz's observations • Hallwachs and Lenard's observation • Dual nature of light
Module 2	• Photocell • Experimental study of photoelectric effect • Photocurrent • Effect of intensity of light on photo current • Effect of positive and negative potential on photocurrent • Stopping potential • Effect of frequency of incident radiation on stopping potential • Interpretations from the graphs drawn from above observations • Photoelectric effect and wave theory of light
Module 3	• Einstein's photoelectric equation • Energy quantum of radiation -the photon • Relating Einstein's photoelectric equation and observations from experiments with photocell
Module 4	• Wave nature of matter • de- Broglie's hypothesis • de-Broglie wavelength • Planck's constant • Probability interpretation to matter waves • Davisson and Germer Experiment • Wave nature of electrons
Module 5	• Application of dual nature of radiation and matter • Electron microscope

Module 5

Words You Must Know

- **Atomic structure**: *Atomic structure* is the positively charged nucleus and the negatively charged electrons circling around it within an *atom.*
- **Electromagnetic waves**: *Electromagnetic waves* are *waves* that are created as a result of vibrations between an electric field and a magnetic field. In other words, ***EM waves* are composed of oscillating magnetic and electric fields**.

- **Electric current**: An *electric current* is a flow of *electric* charge.
- **Ionization of atoms**: It is the process by which an **atom** or a molecule acquires a negative or positive charge by gaining or losing electrons to form **ions**, often in conjunction with other chemical changes.
- **Ray and wave optics**: *Ray optics*, describes light propagation in terms of *rays*. The *ray* in *geometric optics* is an abstraction useful for approximating the paths along which light propagates under certain circumstances. Light propagates in straight-line paths as they travel in different mediums.
- Wave optics is the branch of **optics** that studies interference, diffraction, polarization, and other phenomena for which the **ray** approximation of geometric **optics** is not valid.
- **Plotting and interpreting graphs**: Graphs in the scientific world are between any two physical quantities and show the dependence of one on the other.
- **Analysis and deductions from the graphs** show variations and interpretations can give meaning to the study, for example u-v graphs of experimental observations from optics experiments, not only show the variation and dependence of one physical quantity on another under the constraints of the study.
- **Graphs can be linked with a mathematical equation**: All graphs have a mathematical relation. Hence there will always be an equation related to the segment of the graph drawn; the graph could be a straight line, a curve, a parabola, a hyperbola
- **Photoelectric effect** the emission of electrons from a solid metallic surface when light of suitable frequency is incident on it.
- **Work function**: The minimum amount of energy required by an electron to just escape from the metal surface is known as work function of the metal. This is generally measured in electron volts (eV).
- **Electron volt**: It is the energy gained by an electron when it is accelerated through a potential difference of 1 volt, 1 eV = 1.6×10^{-19} joules
- **Electron emission**: The phenomenon of emission of electrons from a metal surface. This occurs in the following ways.
- **Thermionic emission**: Electrons are emitted from the surface when the surface is heated.
- **Field emission**: Electrons are emitted from a surface when subjected to very high electric field.

- **Photoelectric emission**: Electrons are emitted from a metal surface when electromagnetic radiations of suitable frequency are incident on the surface.
- **Secondary emission**: Electrons are emitted from the surface by striking it with high energy electrons.
- **Photosensitive material**: It was found that certain metals like **zinc, cadmium, magnesium**, etc., responded only to ultraviolet light, having short wavelength, to cause electron emission from the surface. However, some alkali metals such as **lithium, sodium, potassium, caesium and rubidium were sensitive even to visible light.**
- **Photocell Photocell** device that converts light into electrical energy

Results of Experiments with photocell

For a given photosensitive material and frequency of incident radiations (above threshold frequency), **the photoelectric current is directly proportional to the intensity of incident light**.For a given photosensitive material and frequency of incident radiations, **saturation current** is observed to be **proportional to the intensity of incident radiations**, but **the stopping potential depends only on incident frequency**.

For a given photosensitive material, there exists a certain minimum cut-off frequency of incident radiation, (called the threshold frequency), below which no emission of photoelectrons takes place no matter how intense the incident light is. However, above the threshold frequency, the stopping potential, or equivalently the maximum kinetic energy of the emitted photoelectrons increases linearly with the frequency of the incident radiations but is independent of its intensity.

The photoelectric emission is an instantaneous process without any apparent time lag (10^{-9}s or less), even when the intensity of incident radiations (of frequency greater than the threshold frequency) is very small.

Einstein's photoelectric equation $KE_{max} = h\nu - \emptyset_0$

Laws of photoelectric emission

(i) **For a given metal, and a given frequency of incident radiation. (above threshold frequency), the number of photoelectrons emitted per second is proportional to the intensity of incident radiations.**

(ii) **For a given metal, no photoelectrons are emitted if the incident frequency is less than threshold frequency.**

(iii) **Above the threshold frequency, the maximum kinetic energy of emitted photoelectrons is directly proportional to the frequency of incident radiations but is independent of the intensity of incident radiations.**

(iv) **Photoelectric emission is an instantaneous process with a time lag of 10^{-9} s or less.**

- **Wave particle duality** Radiation has dual nature: wave and particle. The nature of experiment determines whether a wave or particle description is best suited for understanding the experimental result. Reasoning that radiation and matter should be symmetrical in nature, Louis Victor de Broglie attributed a wave-like character to matter (material particles). The waves associated with the moving material particles are called matter waves or de Broglie waves.
- **Electron diffraction** Electron diffraction experiments by Davisson and Germer, and by G. P. Thomson, as well as many later experiments, have verified and confirmed the wave-nature of electrons. The de Broglie hypothesis of matter waves supports the Bohr 's concept of stationary orbits.
- **Compton effect** Compton reported his studies on the scattering of X rays by solid materials (mainly graphite) and showed that the shift of the wavelength of the scattered photon could be explained by assuming the photon to have a momentum equal to h/λ. Compton received the Nobel Prize in physics for the discovery of the effect named after him

Introduction

In our consideration of the discovery of photoelectric effect, we studied not only the phenomenon but also the factors that influence the same.

Photoelectric effect is the **phenomenon of emission of electrons by metals when illuminated by light of suitable frequency**. Certain metals respond to ultraviolet light while others are sensitive even to visible light.

Photoelectric effect involves conversion of light energy into electrical energy.

It follows the law of conservation of energy.

The photoelectric emission is an instantaneous process and possesses certain special features.

Photoelectric current depends on

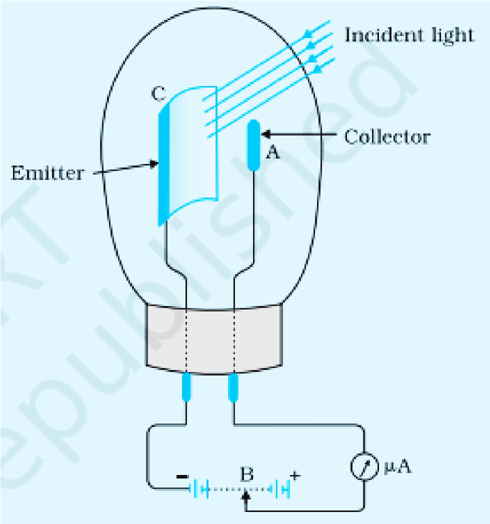
(i) The intensity of incident light,

(ii) The potential difference applied between the two electrodes, and

(iii)The nature of the emitter material.

Photocells

Photo Emissive cell or a **photocell** is a technological application of photoelectric effect. It is also sometimes called an **electric eye.** A photocell consists of a semi-cylindrical photo-sensitive metal plate C (emitter) and a wire loop A (collector) supported in an evacuated glass or quartz bulb. It is connected to the external circuit having a high-tension battery B and micro ammeter (μA) as shown in the Figure.



A photo cell

When light of suitable wavelength falls on the emitter C, photoelectrons are emitted.

These photoelectrons are drawn to the collector A. Photocurrent of the order of a few microamperes can be normally obtained from a photocell.

Important Features of a Photocell are Used in Many Ways

A **change in intensity of illumination results in a change in photocurrent**. This current can be used to operate control systems and in light measuring devices.

A photocell of **lead sulphide** sensitive to infrared radiations is used in **electronic ignition circuits.**

In scientific work, photo cells are used whenever it is necessary to measure the intensity of light. Light meters in photographic cameras make use of photocells to measure the intensity of incident light.

The photocells, inserted in the door light electric circuit, are used as **automatic door openers.** A person, approaching a doorway, may interrupt a light beam which is incident on a photocell. The abrupt change in photocurrent may be used to start a motor which opens the door, or rings an alarm. They are used in the control of a **counting device** which records every interruption of the light beam caused by a person or object passing across the beam. So photocells help count the persons entering an auditorium, provided they enter the hall one by one.

They are used for detection of **traffic law defaulters**: an alarm may be sounded whenever a beam of (invisible) radiation is intercepted.

In a burglar alarm, (invisible) light is continuously made to fall on a photocell installed at the doorway. A person entering the door interrupts the beam falling on the photocell. The abrupt change in photocurrent is used to start an electric bell ringing.

In **fire alarms**, a number of photocells are installed at suitable places in a building. In the event of breaking out of fire, light radiations fall on the photocell. This completes the electric circuit through an electric bell or a siren which starts operating as a warning signal.

Photocells are used in the **reproduction of sound** in motion pictures and in the television camera for scanning and telecasting scenes. In reproduction of sound from a film, light from an exciter lamp is focused on the soundtrack at the side of the moving film and then made to fall on a photocell. The sound track varies the intensity of light passing through it so that the photocell creates varying current which is a replica of that obtained in the recording microphone when the film was made. The fluctuating potential difference across a load resistor is amplified using a loudspeaker. These are used in industries for detecting minor flaws in metals.

Application of Dual Nature of Radiation and Matter

Our eyes use dual nature to see the colourful world around us.

Consider sunlight (white light) incident on innumerable objects the light reflected has definite wavelength and for the rays reaching our eye from the object, the eye forms the real image on the retina.

The rods and cones help us identify the photon energy (hν) giving the sensation of a particular colour

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http://www.dettol.co.in/media/3487/eye-infection-740x400.jpg?width=1140&height=641&center=0.5,0.5&mode=crop

Just for Information

- The **retina** is the innermost, light-sensitive layer, or "coat", of shell tissue of the eye of most vertebrates and some molluscs. The optics of the eye create a focused two-dimensional image of the visual world on the retina, which translates that image into electrical neural impulses to the brain to create visual perception, the retina serving much the same function as film or a CCD in a camera.
- The retina consists of several layers of neurons interconnected by synapses. The neural retina refers to the three layers of neural cells (photoreceptor cells, bipolar cells, and ganglion cells) within the retina, which in its entirety comprises ten distinct layers, including an outer layer of pigmented epithelial cells. The only neural cells that are directly sensitive to light are the photoreceptor cells, which are of two types: rods and cones. **Rods function mainly in dim light and provide black-and-white vision while cones are responsible for the perception of colour. A third type of photoreceptor, the photosensitive ganglion cells, is important for entertainment and reflexive responses to the brightness of light.**
- Light striking the retina initiates a cascade of chemical and electrical events that ultimately trigger nerve impulses that are sent to various visual centres of the brain through the fibres of the optic nerve. Neural signals from the rods and cones undergo processing by other

neurons, whose output takes the form of action potentials in retinal ganglion cells whose axons form the optic nerve.[1] Several important features of visual perception can be traced to the retinal encoding and processing of light.

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Using Photoelectric Effect in a Different Way

The resistance of certain semiconductors, such as cadmium sulphide, decreases as intensity of light falling on it increases.

The effect is due to light photons setting free electrons in the semiconductors, so as to increase their conductivity, i.e., reducing their resistance.

There is a window over a grid like metal structure to allow light to fall on a thin layer of cadmium sulphide, its resistance varies from 10 mega ohm in the dark to 1 kilo ohm in daylight.

These **light dependent resistors (LDR**) are used for study of intensity changes of light under different conditions.

Uses of photocells:

1. **In cinematography for the reproduction of sound.**
2. **To Count 'footfall' at auditoriums, malls, fetes or melas.**
3. **As Burglar's alarm when a person approaching a doorway interrupts a beam of invisible ultraviolet light falling on a photocell, the sudden change in**

photoelectric current starts a motor which opens the door, or rings an alarm for a Fire alarm.

4. **In photographic cameras, light meters are used to indicate the light intensity for selection of aperture.**
5. **Automatic control of street light system, photocells inserted in street lighting system switch on or off depending on daylight intensity, suitable in countries, areas where fog , or cloud cover is there for a large part of the year.**
6. **To operate controls in electronic circuits of television and computers.**
7. **To study temperature and spectra of ovens, stars.**
8. **To control temperature of furnaces and chemical reactions.**
9. **For speed checking by the traffic police.**
10. **Complexion meters, skin flaw detectors used by cosmetic industry for removal of skin pigmentation.**
11. **For determining the opacity of solids and liquid.**
12. **To count vehicles passing a road.**
13. **To count items running on a conveyor belt.**

These and more uses are seen in daily life, you need to be alert and spot them.

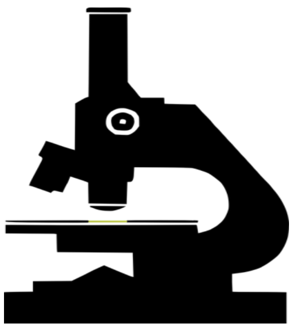
Electron Microscope

More recently, in **1989,** the wave nature of a beam of electrons was experimentally demonstrated in a double-slit experiment, similar to that used for the wave nature of light.

Also, in an experiment conducted in **1994**, interference fringes were obtained with the beams of iodine molecules, which are about a million times more massive than electrons. The de Broglie hypothesis has been basic to the development of modern quantum mechanics. It has also led to the field of electron optics.

The wave properties of electrons have been utilised in the design of electron microscope which is a great improvement, with a much higher resolution, over the optical microscope.

This one can see in the school laboratory or at pathology laboratories



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Consists of lenses of suitable aperture, focal length and material, prims with ability to focus a clear image of a small object placed in front of the objective of the microscope.

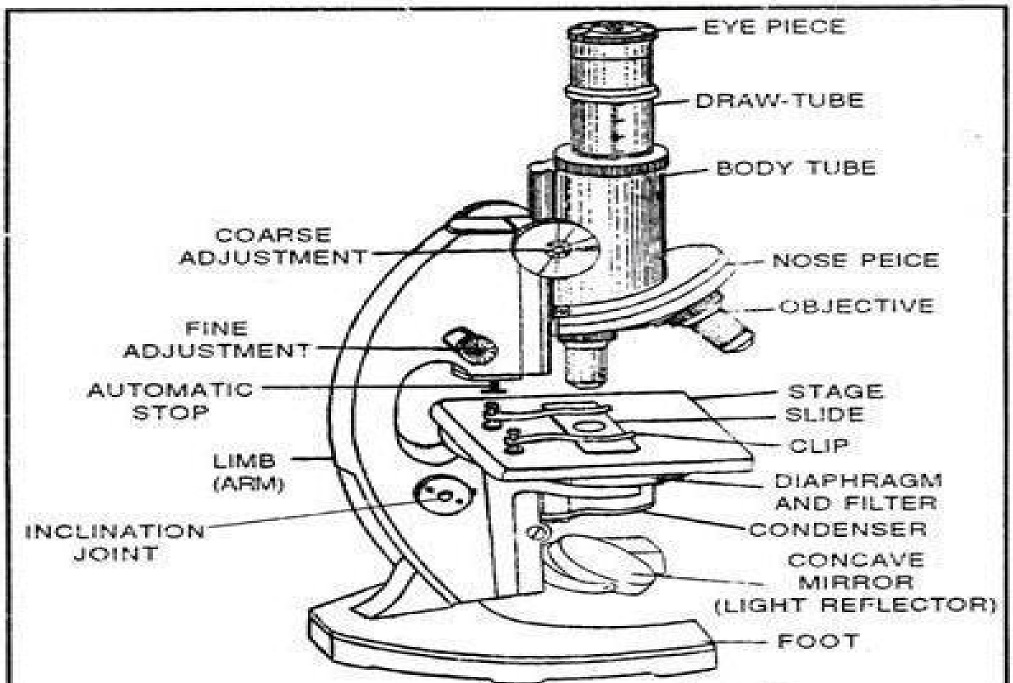

Figure 1.4 A monocular compound or student microscope.

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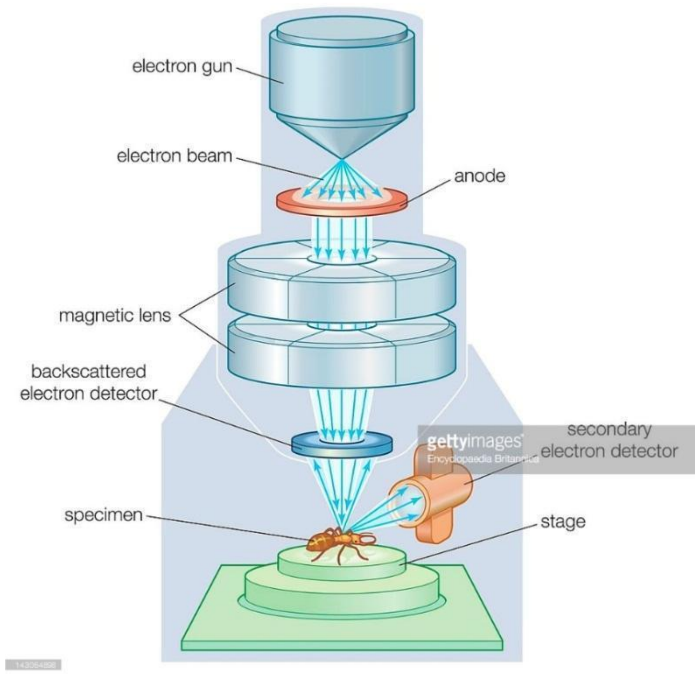
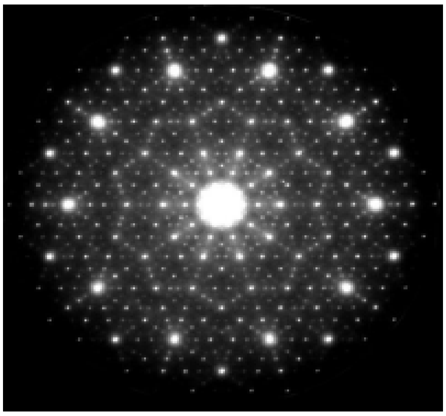
The focussing in electron microscope is done with the help of electric and magnetic field

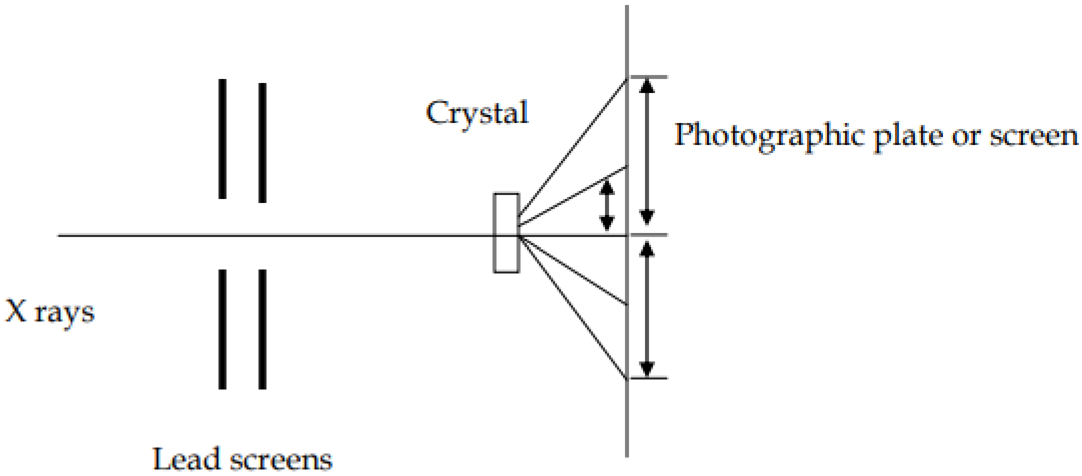


http://media.gettyimages.com/photos/the-components-of-a-scanning-electron-microscope-picture-id143064898

A picture of crystal structure as seen using X–rays and electron waves forming a diffraction pattern. The diffraction pattern confirmed the wavelength of X–rays as 10^{-10} m. Atoms in a crystal can be considered to be arranged in several different sets of parallel planes from all of which strong reflection may be obtained to give an interference pattern giving spots on a photographic plate. The pattern is characteristic of the particular structure.



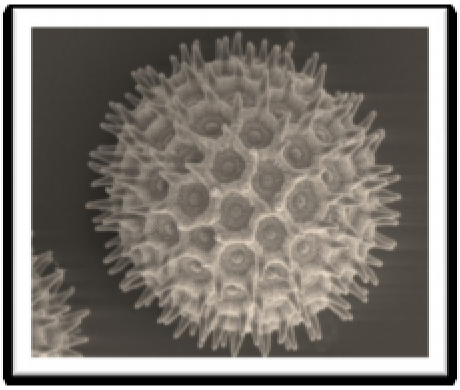
The sheer symmetry of these patterns is amazing.



Schematic arrangement to see diffraction pattern created by X–rays.

Some pictures (as seen under an electron microscope)

Spider



Pollen

Think About These – (based on the concepts learnt in the unit)

- What will be the energy of photons in a beam whose wavelength is 526 nm?
- Determine the vacuum wavelength corresponding to gamma waves of 10^{19} eV.
- What is the photon energy in joules corresponding to a 60 Hz wave emitted from a power line? How does it compare with the energy range for visible light?
- In order to break the chemical bond in the molecules of human skin, causing sunburn, a photon energy of 3.5 eV is required. To what wavelength does this correspond to?
  (Note: hc = 1240 eV)
- Imagine a green bulb of 100W, wavelength = 500 nm. How many photons per second are emerging from the source?
- What is the momentum of a single photon of red light (400×10^{12} Hz) moving through free space? Does its value change in any other medium?
- The work function of sodium is 2.3 eV. Determine the longest wavelength light that can cause photoelectron emission from sodium.
- In the photo ionization of atomic hydrogen, what will be the maximum kinetic energy of the ejected electron when a 60 nm photon is absorbed by the atom? The ionization energy of hydrogen is 13.6 eV.
- Determine de Broglie wavelength of a thermal neutron of mass 1.67×10^{-27} kg when it travels with a speed of 2300m s^{-1}.
- If the de Broglie wavelength of an electron is 1 A^0, determine its velocity and kinetic energy.
- The maximum kinetic energy of a photoelectron is 5 eV. Calculate the stopping potential. Why is this value negative?

- If the intensity of radiation of a given frequency in a photocell is increased, how does the stopping potential vary?
- How does the maximum kinetic energy of electrons emitted vary with the work function of the metal, for the same frequency of incident radiation?
- Work function of sodium is 2.3 eV. Would sodium show photoelectric emission for light of wavelength 6800 A^0?
- Two beams, one of red light and the other of blue light of the same intensity are incident on a metallic surface to emit photoelectrons. Which one of the two would cause emission of electrons of higher kinetic energy?
- Ultraviolet radiations of different frequencies are incident on two photosensitive materials having work functions W_1 and W_2 ($W_1 > W_2$) respectively. The maximum kinetic energy of the emitted photoelectrons is the same in both the cases. Which one of the two radiations will be of higher frequency?
- Express de Broglie wavelength, associated with electrons in terms of the accelerating voltage V.
- If the potential difference used to accelerate electrons is tripled, by what factor does the associated wavelength change?
- de Broglie wavelength, associated with a proton, accelerated through a potential difference V is λ. What will be the de Broglie wavelength when the accelerating potential is increased to 9V?
- An alpha particle and a proton have the same kinetic energy. Which one of the two has a larger associated de Broglie wavelength and why?

Summary

- Radiation has a dual nature: wave and particle.
- The nature of experiment determines whether a wave or particle description is best suited for understanding the experimental result.
- Reasoning that radiation and matter should be symmetrical in nature, Louis Victor de Broglie attributed a wave-like character to matter (material particles).
- The waves associated with the moving material particles are called matter waves or de Broglie waves.

- The de Broglie wavelength (λ) associated with a moving particle is related to its momentum p as: $\lambda = h/p$. The dualism of matter is inherent in the de Broglie relation which contains a wave concept (λ) and a particle concept (p).
- The de Broglie wavelength is independent of the charge and nature of the material particle.
- It is significantly measurable (of the order of the atomic-planes spacing in crystals) only in case of sub-atomic particles like electrons, protons, etc. (due to smallness of their masses and hence, momenta). However, it is indeed very small, quite beyond measurement, in the case of macroscopic objects, commonly encountered in everyday life.
- Electron diffraction experiments by Davisson and Germer, and by G. P. Thomson, as well as many later experiments, have verified and confirmed the wave-nature of electrons.
- Photoelectric effect, dual nature of matter and radiation allow many applications in real life