Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

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Chapter 11: Dual Nature Of Radiation And Matter

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Electron emission:

The phenomenon of emission of electrons from the surface of a metal. The minimum energy needed by an electron to come out from a metal surface is known as “work function” of the metal. It is denoted by Φ or W0 and measured in electron volt (eV).

$$\text{Work function } W = h\nu = \frac{hc}{\lambda}$$

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Electron emission:

The electron emission can be obtained from the following physical processes:

Thermionic emission: It is the phenomenon of emission of electrons from the metal surface when heated suitably.

Photoelectric emission: It is the phenomenon of emission of electrons from the surface of metal when light radiations of suitable frequency fall on it.

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Electron emission:

Field emission or cold cathode emission: It is the phenomenon of emission of electrons from the surface of a metal under the application of a strong electric field.

Photoelectric effect: It is the phenomenon of emission of electrons from the surface of metals when light radiations of suitable frequency fall on them.

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Electron emission:

Work Function:

To pull out electron from the surface of the metal, a certain minimum amount of energy is required. This minimum energy required by the electron is called the work function of the metal. Work function is generally denoted by 'w' and measured in eV (electron volt).

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Electron emission:

Threshold Frequency:

The minimum frequency of light which can emit photoelectrons from a material is called threshold frequency or cut-off frequency of that material.

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Electron emission:

Threshold Wavelength:

The maximum wavelength of light which can emit photoelectrons from a material is called threshold wavelength or cut-off wavelength of that material.

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Electron emission:

Electron Volt:

One electron volt is the energy acquired by an electron, when it has been accelerated by 1-volt potential difference. (1 eV = 1.602 × 10–19 J)

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Photoelectric Effect:

The phenomenon of emission of photoelectron from the surface of metal, when a light beam of

suitable frequency is incident on it, is called photoelectric effect. The emitted electrons are called photoelectrons and the current so produced is called photoelectric current.

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Laws of Photoelectric Effect:

- For a given metal and a radiation of fixed frequency, the number of photoelectrons emitted is proportional to the intensity of incident radiation.
- For every metal, there is a certain minimum frequency below which no photoelectrons are emitted, howsoever high is the intensity of incident radiation. This frequency is called threshold frequency.

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Laws of Photoelectric Effect:

- For the radiation of frequency higher than the threshold frequency, the maximum kinetic energy of the photoelectrons is directly proportional to the frequency of incident radiation and is independent of the intensity of incident radiation.

- The photoelectric emission is an instantaneous process.

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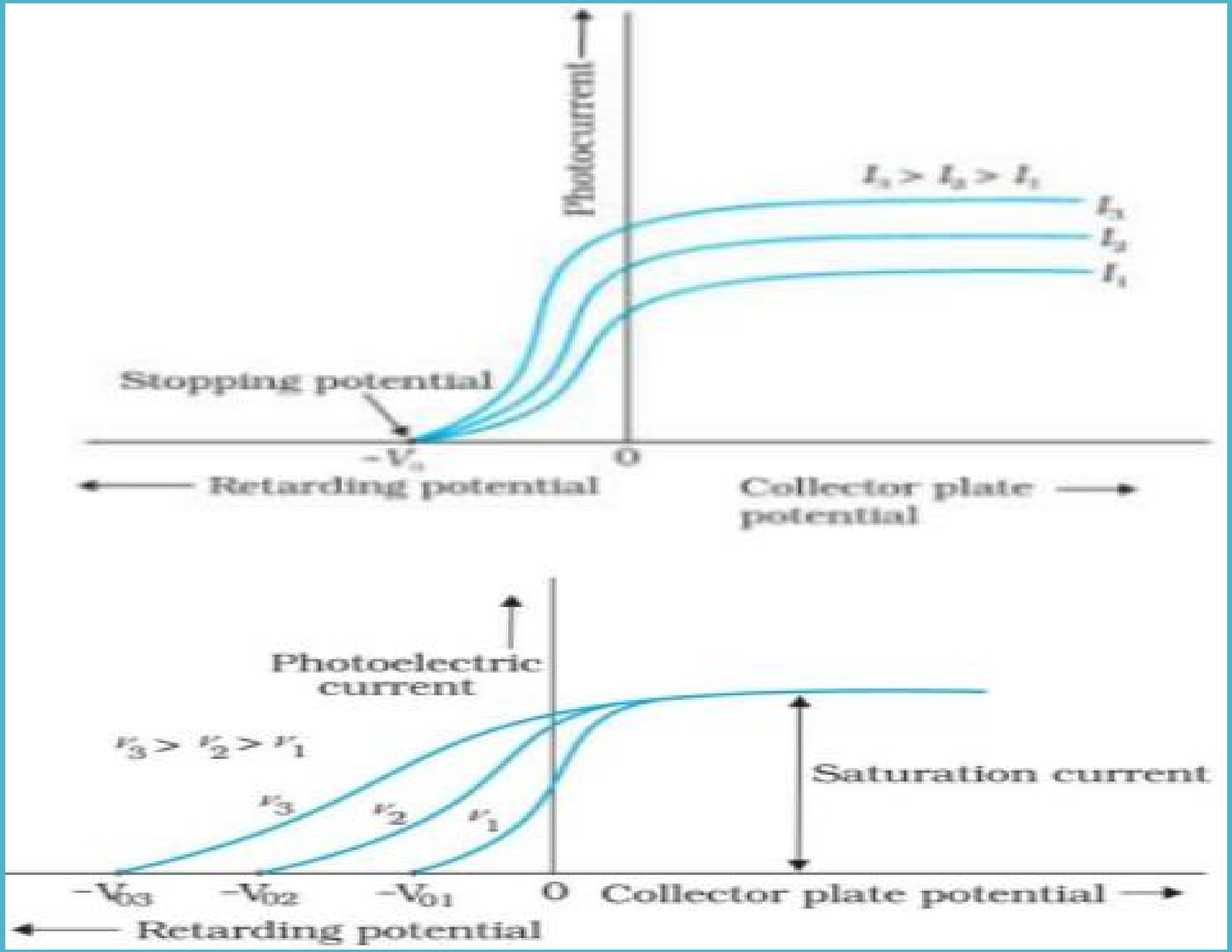
Laws of Photoelectric Effect:



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Hertz' Observation:

The phenomenon of photo electric emission was discovered in 1887 by Heinrich Hertz during his electromagnetic wave experiment. In his experimental investigation on the production of electromagnetic waves by means of spark across the detector loop were enhanced when the emitter plate was illuminated by ultraviolet light from an arc lamp.

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Lenard's Observation:

Lenard observed that when ultraviolet radiation was allowed to fall on emitter plate of an evacuated glass tube enclosing two electrodes, current flows. As soon as, the ultraviolet radiations were stopped, the current flows also stopped.

These observations indicate that when ultraviolet radiations fall on the emitter plate, electrons are ejected from it which are attracted towards the positive plate by the electric field.

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Cathode Rays:

Cathode rays are the stream of fast-moving electrons. These rays are produced in a discharge

tube at a pressure below 0.01 rom of mercury.

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Properties of Cathode Rays:

- Cathode rays are not electromagnetic rays.
- Cathode rays are deflected by electric field and magnetic field.
- Cathode rays produce heat in metals when they Fallon them.
- Cathode rays can pass through thin aluminium or gold foils without puncturing them.

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Properties of Cathode Rays:

- Cathode rays can produce physical and chemical change.
- Cathode ray travel in straight line with high velocity momentum and energy and cast shadow of objects placed in their path.
- On striking the target of high atomic weight and high melting point, they produce X-rays.
- Cathode rays produce fluorescence and phosphorescence in certain substance and hence affect photographic plate.

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Positive Rays:

Positive rays were discovered by Goldstein. Positive rays are moving positive ions of gas filled in the discharge tube. The mass of these particles is nearly equal to the mass of the atoms of gas.

- These consist of fast moving positively charged particles.
- These rays are deflected in magnetic and electric fields.

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Positive Rays:

- These rays travel in straight line.
- Speed of positive rays is less than that of cathode rays.
- These rays can produce fluorescence and phosphorescence.

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Dual nature of radiation:

Wave theory of electromagnetic radiation explains the phenomenon of interference, diffraction, and polarization. On the other hand, photoelectric effect is supported by particle nature of light.

Hence, we assume dual nature of light.

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Einstein's Photoelectric Equation:

To explain photoelectric effect in 1905, Albert Einstein proposed completely different picture of electromagnetic radiation. In this picture radiation energy is built up of discrete units and photoelectric emission does not take place by continuous absorption of energy from radiation.

These discrete units are called quanta of energy of radiation. Each quantum of energy is hv, where v is the frequency of light and h is Planck's constant.

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Einstein's Photoelectric Equation:

In photoelectric effect, an electron absorbs a quantum of energy (hv) of radiation. If this absorbed energy exceeds the minimum energy (work function 'w' of the metal), the most loosely bound electron will emerge with maximum kinetic energy, more tightly bound electron will emerge with kinetic energies less than the maximum value.

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Einstein's Photoelectric Equation:

Einstein's photoelectric equation

$$E_k = h\nu - \omega$$

$$E_k = h\nu - h\nu_0$$

$$E_k = h(\nu - \nu_0)$$

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X-rays:

When cathode rays strike on a heavy metal of high melting point. then a very small fraction of its energy converts into a new type of waves, called X-rays.

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Properties of X-rays:

- X-rays were discovered by Roentgen.
- X-rays are electromagnetic waves of wavelengths ranging from 0.1 A to 100 A and frequencies ranging from 1016 Hz to 1018 Hz.
- Soft X-rays have greater wavelength and lower frequency.
- Hard X-rays have lower wavelength and higher frequency.

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Properties of X-rays:

- X-rays are produced by Coolidge tube.
- Molybdenum and tungsten provide suitable targets. These elements have large atomic number and high melting point for the purpose.
- The intensity of X – rays depend on the heating voltage or filament current.

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Moseley's Law:

The frequency of X-ray is given by

$$V = a\,(Z - b)^2$$

where a and b are constants and Z is atomic number of element.

Frequency of X-rays

$$v \propto Z^2$$

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Wave Nature of Matter:

The wave nature of light shows up in the phenomena of interference, diffraction and polarization. De Broglie proposed that the wavelength λ associated with a particle of momentum p is given as.

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

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Photocell:

- It is an arrangement which converts light energy into electric energy.
- It works on the principle of photoelectric effect.
- It is used in cinematography for the reproduction of sound.

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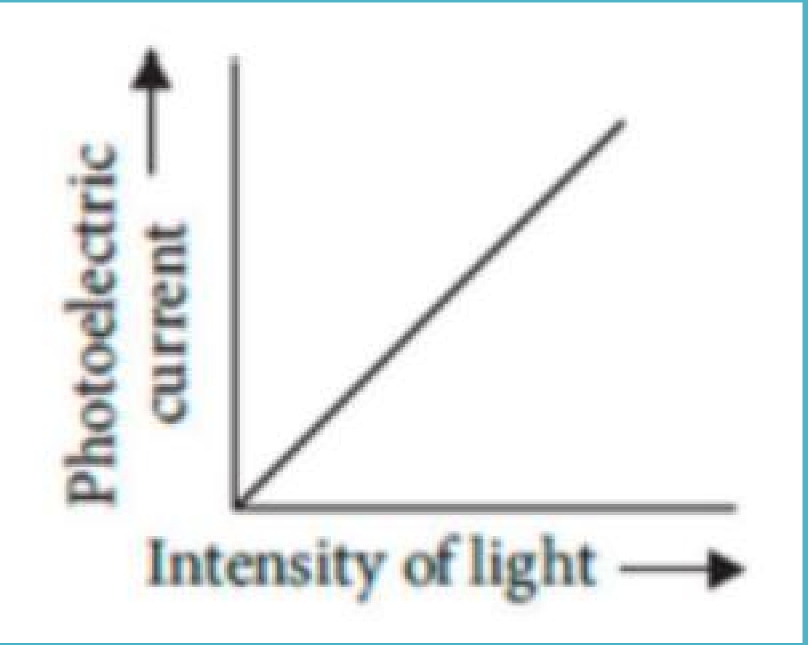
Photoelectric current:

Photoelectric current depends on the intensity of incident light and the potential difference applied between the two electrodes.



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Particle Nature of Light:

Photoelectric effect thus gave evidence to the strange fact that light in interaction with matter behaved as if it was made of quanta or packets of energy, each of energy hv. A definite value of energy as well as momentum is associated with a particle. This particle was later named photon.

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We can summaries the photon picture of electromagnetic radiation as follows:

- **In interaction of radiation with matter, radiation behaves as if it is made up of particles called photons.**
- **Each photon has energy $E\ (= h\nu)$ and momentum $p\ \left(= \frac{h\nu}{c}\right)$, and speed c, the speed of light.**

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We can summaries the photon picture of electromagnetic radiation as follows:

- All photons of light of a particular frequency v, or wavelength #, have the same energy $E\left(= h\nu = \frac{hc}{\lambda}\right)$

and momentum $p\left(= \frac{h\nu}{c} = \frac{h}{\lambda}\right).$

Photons are electrically neutral and are not deflected by electric and magnetic fields.

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We can summaries the photon picture of electromagnetic radiation as follows:

- **In a photon-particle collision (such as photon-electron collision), the total energy and total momentum are conserved.**

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Davisson and Germer Experiment:

The wave nature of electrons was first experimentally verified independently by C. J. Davisson and L. H. Germer in 1927 and by G. P. Thomson in 1928 while observing diffraction effects with beams of electrons scattered by crystals. The experimental arrangement is schematically shown in figure.

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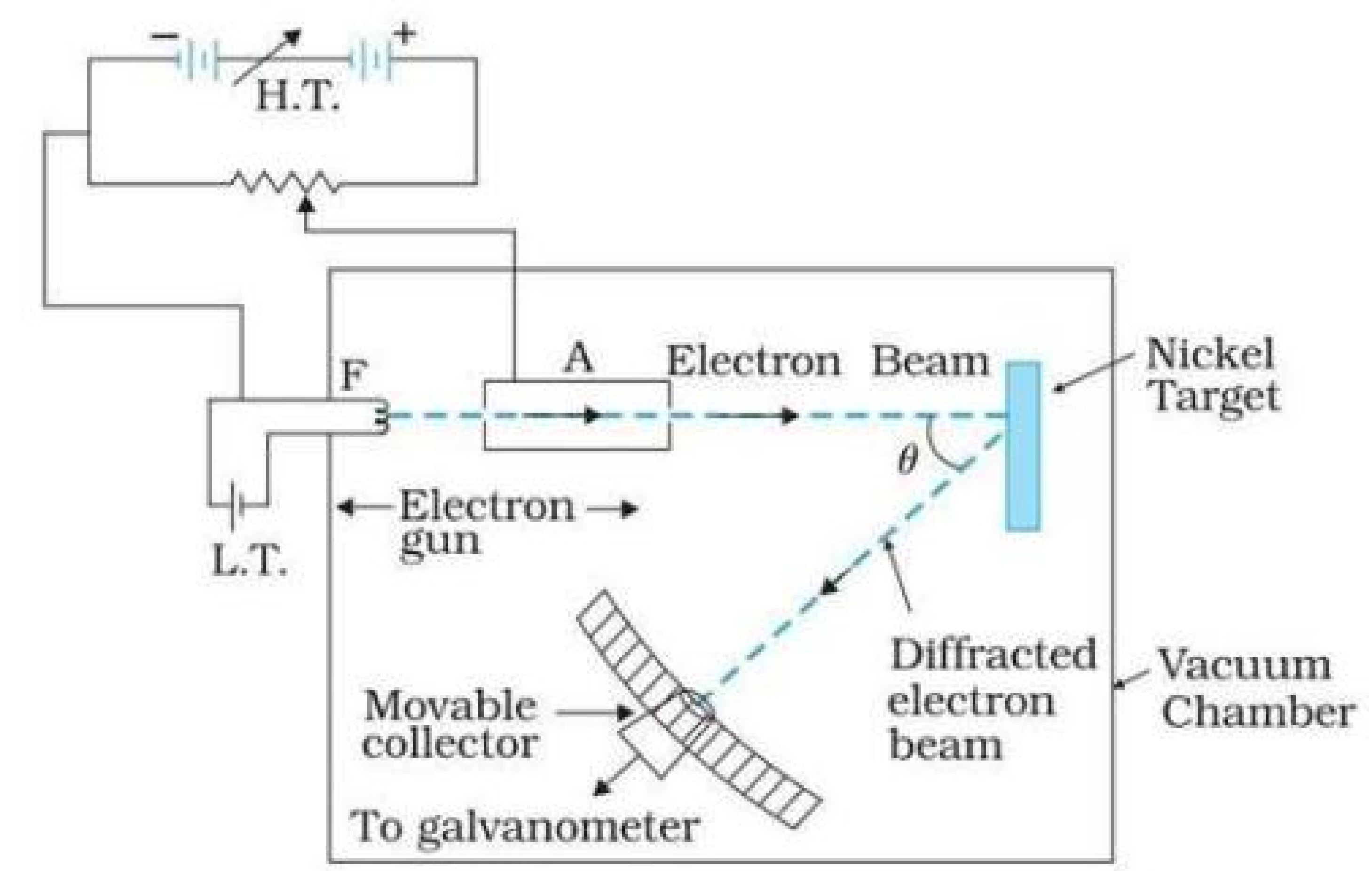
Davisson and Germer Experiment:



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Davisson and Germer Experiment:

It has an electron gun made up of a tungsten filament F, heated by a low voltage battery and the filament is coated with barium oxide. Emitted electrons from filament are accelerated to a desired velocity by applying required potential/ voltage from a high-voltage power supply. C is a hollow metallic cylinder with a hole along the axis and is kept at negative potential to get a convergent beam of electrons emitted from filament. It acts as a cathode. A is a cylinder with fine hole along its axis acting as an anode.

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Davisson and Germer Experiment:

The cathode and anode form an electron gun by which a fine beam of electrons can be obtained of different velocities by applying different accelerating potentials. N is a nickel crystal cut along cubical diagonal, D is an electron detector which can be rotated on a circular scale and is

connected to a sensitive galvanometer which records the current.

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Davisson and Germer Experiment:

Working:

From electron gun a fine beam of accelerated electrons is made to fall normally on the surface of nickel crystal. The atoms of the crystal scatter the incident electrons in different directions. The detector detects the intensity of the electron beam scattered direction by rotating the electron detector on circular scale at different positions.

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Davisson and Germer Experiment:

According to de Broglie hypothesis, the wavelength of the wave associated with electron is given by.

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

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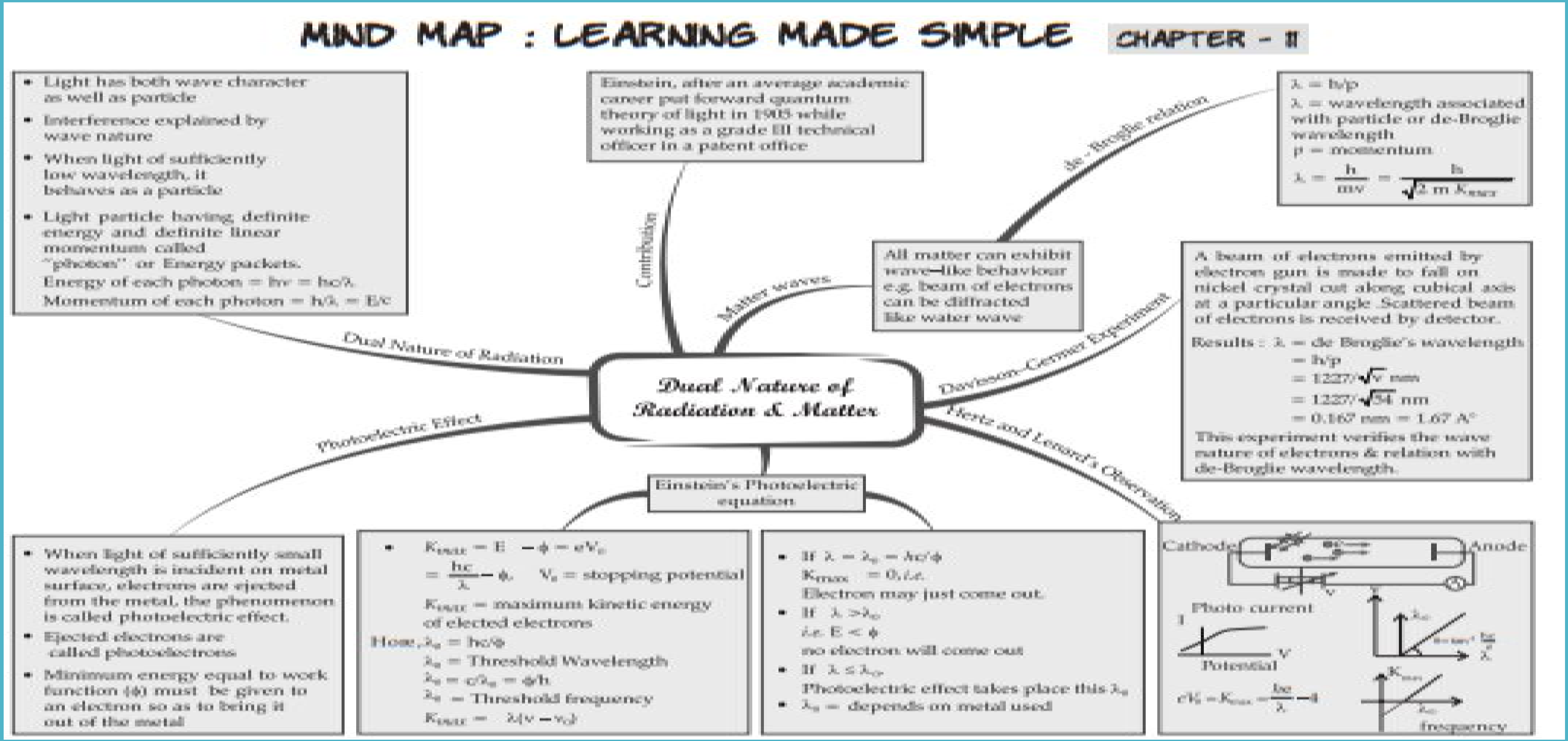

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