Chapter 2: Dual Aspects

Lecture 7

7.1 Particle Aspects of EM Radiation

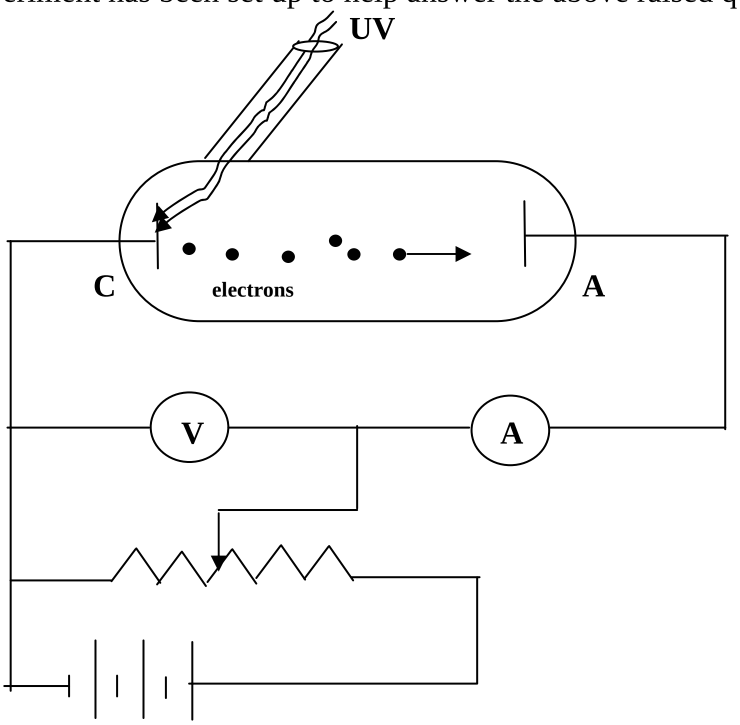
In order to explain the results of some phenomena, one has to associate wave aspects to particles (scattering of electron beam $\Rightarrow$ electronic microscope) and to associate particle aspects to EM radiation (photoelectric effect). Furthermore, according to the quantum theory, light is found to be of discrete nature, i. e. composed of pulses of waves or corpuscles, each carries a definite quantity of energy, hence termed a quanta and called a photon.

7.2 Photoelectric Effect

Upon shining the surfaces of some metals like zinc and cesium, electrons come out and produce a measurable electric current. This may be explained knowing that light carries energy and some of its energy must have imparted to the electrons which eventually get dislodged. At this stage we may raise three main issues:

1. The velocity with which electrons get dislodged…
2. The number of dislodged electrons for known set up….
3. The time an electron takes to get dislodged…..

An experiment has been set up to help answer the above raised questions,



When UV light impinges the metal of the cathode, electrons get released and collected at the anode by the aid of a potential difference supplied by the shown potential divider. This current is called a photoelectric current and can be measured by the ammeter A for a given voltage V. The photoelectric current is found to be dependent on:

1. The intensity of the incident light I.
2. The wavelength of the incident light λ.

Let us now study the effect of I and λ, one at a time.

- Effect of the intensity I

For a monochromatic light of wavelength λ, if the intensity of the incident light is changed and the current is recorded for every I. The photoelectric current is then plotted against I, the following plots are obtained.

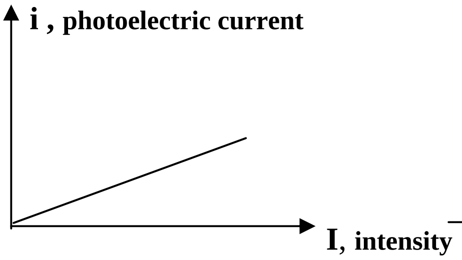


Fig. 1.

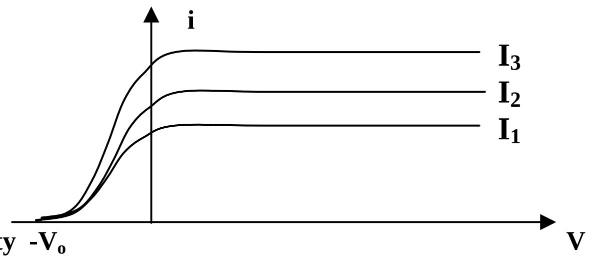


Fig. 2.

It is clear that as the intensity of the light increases, the photoelectric current increases, Fig. 1. Figure 2 shows that there was a well defined minimum voltage that stopped any electrons getting through, we'll call it a stopping potential V_o. Surprisingly, V_o does not depend at all on the intensity of the light! Doubling the light intensity doubled the number of electrons emitted, but did not affect the energies of the emitted electrons.

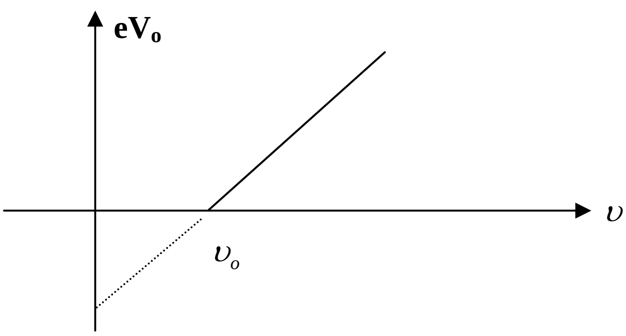
One can then draw two main conclusions:

1. The photoelectric current, i. e. the number of ejected electrons per second, is directly proportional to the intensity of the light to a given wavelength.
2. For a given wavelength, the kinetic energy of photoelectrons does not exceed a certain maximum value:

$$\frac{1}{2}mv^2 = eV_o$$

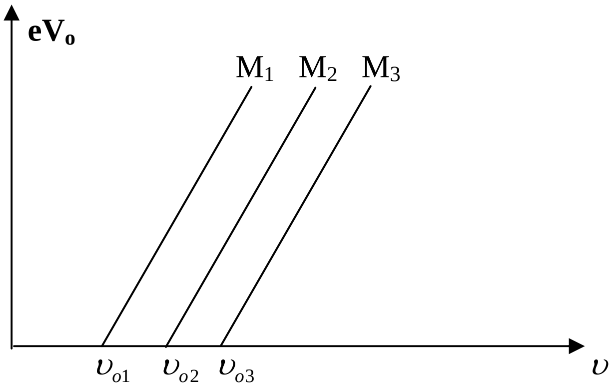
- Effect of the wavelength λ

The stopping potential is now recorded for different wavelengths. The following graph is obtained.



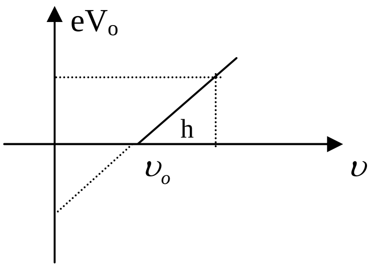
It is found that for a certain cathode material, there is a minimum frequency υ_o after which photoelectrons are ejected and an electric current flows.

If different materials are considered for the cathode a set of parallel line are obtained as shown:



The slope is constant and is termed Planck's constant $h=6.63\times10^{-34}$J.s. One can write down a relation between eV_o and υ as follows.

$eV_o = h\upsilon - h\upsilon_o$



So if a photon of frequency υ is impinging upon a metal surface whose threshold frequency υ_o, the photoelectron will have a maximum kinetic energy of

$$eV_o = \frac{1}{2}mv^2_{\max} = h\upsilon - h\upsilon_o$$

7.3 Conclusions:

1. The energy distribution of the ejected photoelectrons does not depend on the intensity of the incident light. The intensity of the incident light changes the number of the ejected electrons for a certain frequency, but the average energy stays the same.
2. The time delay between the moment the light is shined and the emergence of photoelectrons is almost negligible.
3. As the frequency of incident light increases, the energy of the dislodged electrons increases.