

Quadrant II – Transcript and Related Materials

Programme: Bachelor of Science (Second Year)

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Unit: 4- Properties of Electromagnetic radiation

Module Name: Photoelectric effect

Module No: 14

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Notes

Electrons are emitted from a metal surface when light of sufficiently high frequency (ultraviolet light for all but alkali metals) falls upon it. This phenomenon is known as the ***photoelectric effect***, and was discovered by Heinrich Hertz in 1887. The emitted electrons are known as ***photoelectrons***.

An evacuated tube (photoelectrons won't lose energy in collisions with molecules of air) contains two electrodes connected to an external circuit, with the metal plate whose surface is to be irradiated as the anode.

The anode is photoelectrically sensitive. Some of the photoelectrons that emerge from the irradiated surface have sufficient energy to reach the cathode despite its negative polarity and they constitute the current measured across the ammeter in the circuit.

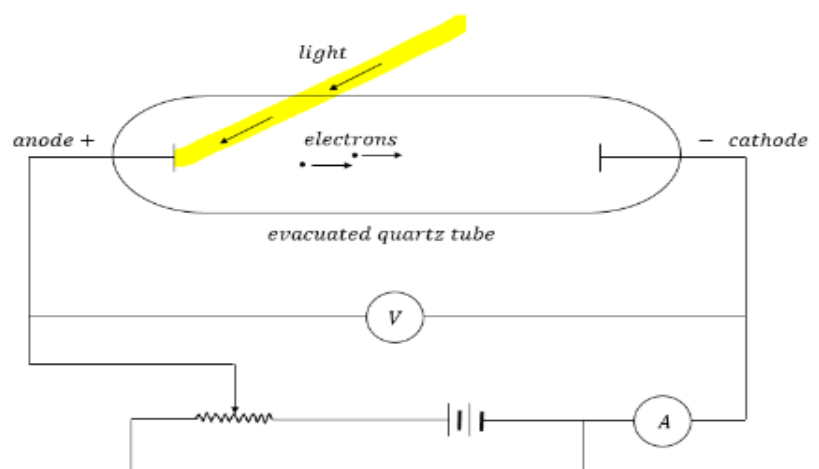


Figure 1: Experimental observation of the photoelectric effect

The rate of electron emission and maximum kinetic energy of the photoelectrons can be measured.

- The rate of electron emission is measured as an electric current by an ammeter in the external circuit.
- The maximum kinetic energy of the electrons can be measured by applying a negative potential to the cathode that is just enough to repel the most energetic electrons. If the potential difference between the anode and the cathode is ΔV , the electrons on traveling from the anode to the cathode would gain a potential energy of $\Delta U = -e\Delta V$ (a positive quantity) and would lose the same amount of kinetic energy.

As the magnitude of the potential difference is increased, at some point even the most energetic electrons do not have enough kinetic energy to reach the cathode. This potential is termed as the **stopping potential (extinction voltage) V^0** and is determined by increasing the magnitude of the voltage until the ammeter current drops to zero. At this point the maximum kinetic energy $T_{max} = eV^0$ where e is the magnitude of electric charge of the electron. It is clear that the relationship between T_{max} and the frequency ν involves a proportionality and can be expressed as

$$T_{max} = h\nu - h\nu_0 = h(\nu - \nu_0)$$

Where ν_0 is the threshold frequency and $h = 6.63 \times 10^{-34} Js$.

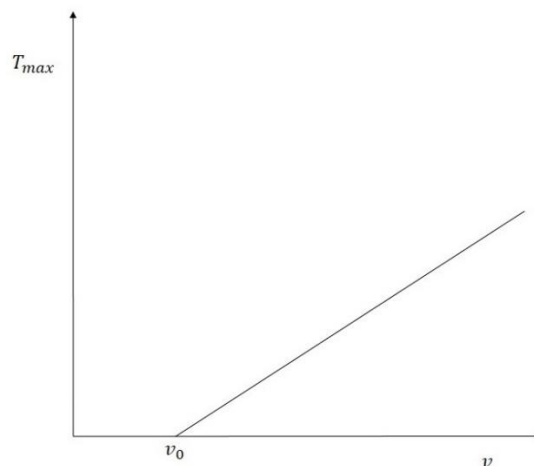


Figure2: The maximum photoelectron energy as a function of frequency of the incident light.

NOTE: The electrons emitted need not have the same kinetic energies. The kinetic energies of the photoelectrons depend on how tightly bound they are to the metal. Here we are concerned only with the maximum kinetic energy, which depends on the energy needed to remove the least tightly bound electron from the surface of the metal.

Laws of photoelectric emission

(i) For every metal, there is a particular minimum frequency of the incident light, below which there is no photoelectric emission, whatever be the intensity of radiation. This minimum frequency, which can cause photoelectric emission is called the threshold frequency ν_0 .

(ii) The strength of the photoelectric current is directly proportional to the intensity of the incident light, provided the frequency is greater than the threshold frequency.

A strong light beam yields more photoelectrons than a weak one of the same frequency.

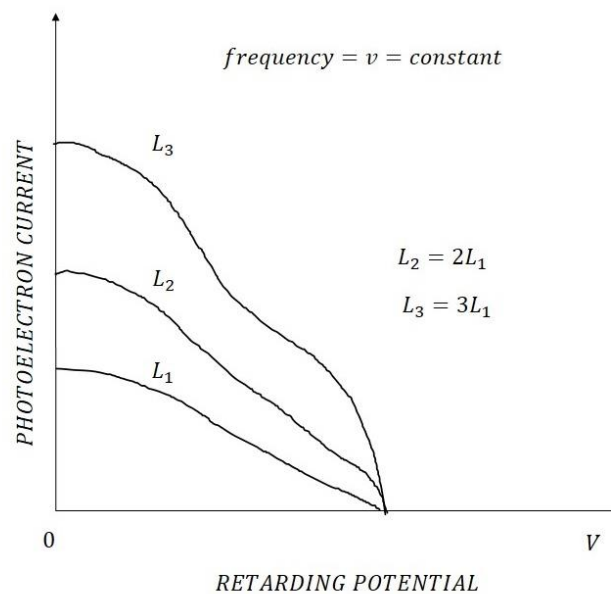


Figure 3: Photoelectron current is proportional to the light L for all retarding voltages. The extinction voltage V^0 is the same for all intensities of light of a given frequency ν .

(iii) The velocity and hence the energy of the emitted photoelectrons is independent of the intensity of light and depends on the frequency of the incident light and the nature of the metal.

At frequencies below the threshold frequency of each particular metal, no electrons are emitted. Above this threshold frequency the photoelectrons have a range of energies from 0 to a certain maximum value and this maximum energy increases linearly with increasing frequency. High frequencies result in high maximum photoelectron energies, low frequencies in low maximum photoelectron energies.

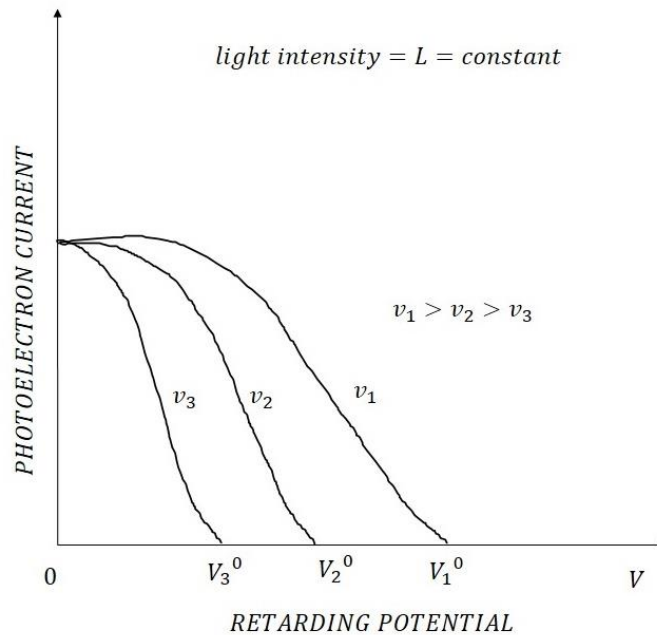


Figure 4: The extinction voltage V^0 depends upon the frequency ν of the light. When the retarding potential is $V = 0$, the photoelectric current is the same for light of a given intensity L regardless of the frequency.

(iv) Photoelectric emission is an instantaneous process. The time lag, if any, between incidence and emission of electrons, is never more than 3×10^{-9} sec.

Failure of classical physics and electromagnetic theory

The above experimental facts could not be explained on the basis of classical physics and electromagnetic theory.

- Calculations showed that it would require about 500 days to dislodge a photoelectron from sodium by exposure to violet light of wavelength 4000\AA . Experimentally, however, we observe that electron ejection commences without delay.
- According to classical theory, light of greater intensity should impart greater kinetic energy to the liberated electrons. But, this does not happen. Also, the velocity of the emitted electrons should not depend on the frequency of the incident light. But it does.

The phenomenon was adequately explained by Einstein on the basis of Planck's Quantum theory of radiation.