Modern Physics Lab PHYS 396 — "The Photoelectric effect "

September 19, 2017

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Introduction

The work of Maxwell and Hertz in the late 1800s conclusively showed that light, heat radiation, and radio waves were all electromagnetic waves differing only in frequency and wavelength. Thus it astonished scientists to find that the spectral distribution of radiation from a heated cavity could not be explained in terms of classical wave theory. Such that the energy carried by an electromagnetic wave is proportional to the magnitude of the Poytong vector

$$\vec{S} = \frac{1}{\mu}\left(\vec{E} \wedge \vec{B}\right) \tag{1}$$

That is the energy of electromagnet waves is proportional to the intensity of the 'light'

$$\mathcal{E} \propto I \sim |\vec{E}|^2 \tag{2}$$

However, this relation caused 'divergences' in the explanation of the blackbody spectrum calculation (known as the UV- catastrophe).
Planck was forced to introduce the concept of the quantum of energy in order to derive the correct blackbody formula. According to Planck, the atomic oscillators responsible for blackbody radiation can have only discrete, or quantized, energies given by

$$E = nh\nu \tag{3}$$

where n is an integer, h is PlanckâĂŹs constant, and ν is the oscillatorâĂŹs natural frequency. Planck quantized the energy of atomic oscillators, but Einstein extended the concept of quantization to light itself. In EinsteinâĂŹs view, light of frequency ν consists of a stream of particles, called photons, each with energy $E = h\nu$. The photoelectric effect, a process in which electrons are ejected from a metallic surface when light of sufficiently high frequency is incident on the surface. It contradicts with the classical theory in the following points:

1. No photoelectrons are emitted from the metal when the incident light is below a minimum frequency, regardless of its intensity. (The value of the minimum frequency is unique to each metal.)
2. Photoelectrons are emitted from the metal when the incident light is above a threshold frequency. The kinetic energy of the emitted photoelectrons increases with the frequency of the light.
3. The number of emitted photoelectrons increases with the intensity of the incident light. However, the kinetic energy of these electrons is independent of the light intensit
4. Photoemission is effectively instantaneous (happen in a very quick time, without heating)

But the photoelectric effect observations can be simply explained with the photon theory. According to Einstein theory, the maximum kinetic energy of the ejected **photoelectron**, T_{max}, is given by

$$T_{max} = h\nu - \phi, \tag{4}$$

where ϕ is the work function of the metal.

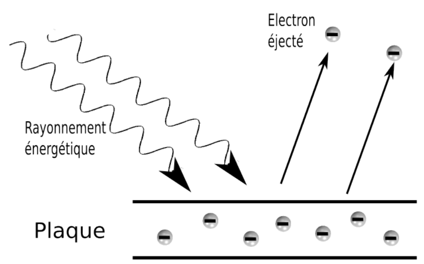

Figure 1: The photoelectric effect

Theory

Consider the conduction electrons in a metal to be bound in a well-defined potential. The energy required to release an electron is called the work function ϕf the metal. In the classical model, a photoelectron could be released if the incident light had sufficient intensity. However (4) requires that the light exceed a threshold frequency ν_{th} for an electron to be emitted If $\nu > \nu_{th}$, then a single light quantum (called a photon) of energy $\mathcal{E}i = h\nu$ is sufficient to liberate an electron, and any residual energy carried by the photon is converted into the kinetic energy of the electron. Thus, from energy conservation, $\mathcal{E} = \phi + T$ or

$$T_{max} = \frac{1}{2}m_e v^2 = \mathcal{E} - \phi = h\nu - \phi \tag{5}$$

When the incident light intensity is increased, more photons are available for the release of electrons, and the magnitude of the photoelectric current increases. From the previous equation , we see that the kinetic energy of the electrons is independent of the light intensity and depends only on the frequency.
The photoelectric current in a typical setup is extremely small, and making a precise measurement is difficult. Normally the electrons will reach the anode(positive part) of the photodiode, and their number can be measured from the (minute) anode current. However, we can apply a reverse voltage to the anode; this reverse voltage repels the electrons and prevents them from reaching the anode. The minimum required voltage is called the stopping potential V_s, and the 'stopping energy' of each electron is therefore V_s. Thus,

$$eV_s = h\nu - \phi \tag{6}$$

or

$$V_s = \frac{h}{e}\nu - \frac{1}{e}\phi \tag{7}$$

This equation shows a linear relation, observe that

$$\underbrace{V_s}_{\text{dependent variable } y} = \underbrace{\frac{h}{e}}_{\text{slope } a} \underbrace{\nu}_{\text{independent variable } x} - \underbrace{\frac{1}{e}\phi}_{\text{y-intecept} b}$$

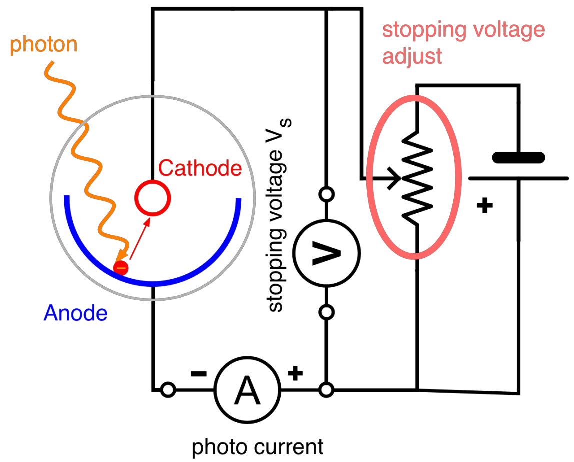

Figure 2: The experiment general setup

Hence, if the value of the electron charge ee is known, then this equation provides a good method for determining Planck's constant h. In this experiment, we will measure the stopping potential with different light frequencies.

Reference

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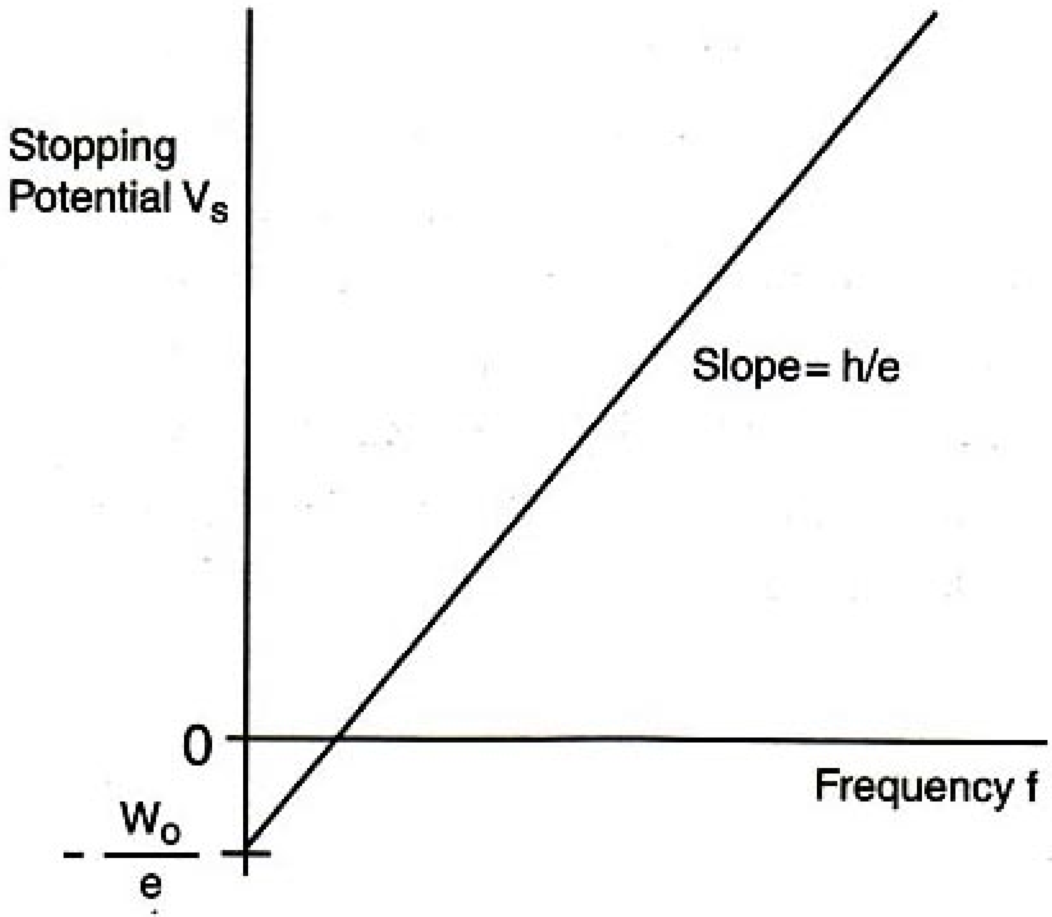

Figure 3: The relation between the stopping potential V_s and light frequency ν provided that $\nu > \nu_{th}$