The Photoelectric Effect without Photons

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Abstract: Using the same ideas and approach followed in our derivation of *Planck's Law is an exact mathematical identity* and our explanation of the *double-slit experiment*, we in this note provide an explanation of the *Photoelectric Effect* and derive equations that conform well with experimental data.

Introduction: In another paper we have proven the following mathematical results.

Theorem 1: $$E(t) = E_0 e^{\nu t} \text{ if and only if } E_0 = \frac{\eta \nu}{e^{\eta \nu / \kappa \mathcal{T}} - 1} \qquad \textbf{(1)}$$

where $E(t)$ is integrable, $\eta = \int_0^\tau E(u)du$, $\mathcal{T} = \left(\frac{1}{\kappa}\right)\frac{\eta}{\tau}$ and κ is an arbitrary constant.

Theorem 1a: $$\lim_{\tau \to 0} \frac{\eta \nu}{e^{\eta \nu / \kappa \mathcal{T}} - 1} = E_0 \text{ , or that } E_0 \approx \frac{\eta \nu}{e^{\eta \nu / \kappa \mathcal{T}} - 1} \qquad \textbf{(2)}$$

where $E(t)$ any integrable function

Theorem 2: $$E(t) = E_0 e^{\nu t} \text{ if and only if } \Delta E = \eta \nu \qquad \textbf{(3)}$$

where $\Delta E = E(t) - E(t_0)$ and $\eta = \int_{t_0}^{t} E(u)du$

From *Theorem 1 (or 1a)* we can derive *Planck's Law* for blackbody radiation,

$$E_0 = \frac{h\nu}{e^{h\nu/kT} - 1} \qquad \textbf{(4)}$$

while *Theorem 2* establishes the *Quantum of Energy Hypothesis,* $\Delta E = nh\nu$. **(5)**

Planck's Law in conjunction with *Theorem 1* above leads to the following,

Time-dependent Local Representation of Energy:

$$E(t) = E_0 e^{\nu t} \qquad \textbf{(6)}$$

where E_0 is the intensity and ν is the frequency of radiation.

We can also show that the *pulse of time* τ required for an accumulation of energy *h* to occur is given by,

$$\tau = \frac{h}{kT} \qquad \textbf{(7)}$$

where *h* is Planck's constant, *k* is Boltzmann's constant and *T* is temperature (Kelvin)

The Photoelectric Effect:

Photoelectric emission has typically been characterized by the following experimental facts *(some of which can be disputed, as noted)*:

1. For a given metal surface and frequency of incident radiation, the rate at which photoelectrons are emitted (the photoelectric current) is directly proportional to the intensity of the incident light.
2. The energy of the emitted photoelectron is independent of the intensity of the incident light but depends on the frequency of the incident light.
3. For a given metal, there exists a certain minimum frequency of incident radiation below which no photoelectrons are emitted. This frequency is called the threshold frequency. *(can be disputed)*
4. The time lag between the incidence of radiation and the emission of photoelectrons is very small, less than 10^{-9} second.

Explanation of the Photoelectric Effect without the Photon Hypothesis:

Let ν be the frequency (rate) of radiation of an incident light on a metal surface and let α be the frequency (rate) of absorption of this radiation by the metal surface. The combined rate locally at the surface will then be $\nu - \alpha$ and using the representation of energy **(6)** above, the radiation energy at the surface can be represented by $E(t) = E_0 e^{(\nu - \alpha)t}$, where E_0 is the intensity of radiation of the incident light. If we let P be the 'accumulation of energy' locally at the surface over a time pulse τ, then by **(3)** we'll have that,

$$\Delta E = P(\nu - \alpha) \tag{8}$$

If we let Planck's constant h be the 'accumulation of energy' for an electron, the number of electrons n_e over the pulse of time τ will then be $n_e = \dfrac{P}{h}$ and the energy of an electron ΔE_e will be given by

$$\Delta E_e = \frac{\Delta E}{n_e} = h(\nu - \alpha) \tag{9}$$

Since $P = \int_0^\tau E_0 e^{(\nu - \alpha)u} du = E_0 \left[\dfrac{e^{(\nu - \alpha)\tau} - 1}{(\nu - \alpha)} \right]$, we can calculate the photoelectric current I to be

$$I = \frac{n_e}{\tau} = \frac{P}{h\tau} = E_0 \left[\frac{e^{(\nu - \alpha)\tau} - 1}{h(\nu - \alpha)\tau} \right] \tag{10}$$

The absorption rate α is a characteristic of the metal surface, while the pulse of time τ is assumed to be constant for fixed experimental conditions. The quantity

$$\left[\frac{e^{(\nu - \alpha)\tau} - 1}{h(\nu - \alpha)\tau} \right] \tag{11}$$

would then be *constant*.

Combining the above and using **(9)** and **(10)** we have *The Photoelectric Effect:*

1. **1)** For incident light of fixed frequency ν and fixed metal surface, the photoelectric current I is proportional to the intensity E_0 of the incident light. (by **(10)** and **(11)** above))
2. **2)** The energy ΔE_e of a photoelectron depends only on the frequency ν and not on the intensity E_0 of the incident light. It is given by the equation $\Delta E_e = h(\nu - \alpha)$ where h is Planck's constant and the absorption rate α is a property of the metal surface. (by **(9)** above)
3. **3)** If ΔE_e is taken to be the kinetic energy of a photoelectron, then for incident light with frequency ν less than the 'threshold frequency' α the kinetic energy of a photoelectron would be negative and so there will be no photoelectric current. (by **(9)** above) *(see below for more on this)*
4. **4)** The photoelectric current is almost instantaneous ($< 10^{-9}$ sec.), since for a single photoelectron we have that $\Delta t = \dfrac{h}{kT} < 10^{-9}$ sec. by equation **(7)** above.

Experimental Graphical Analysis: (*preliminary)*

Many experiments since the classic 1916 experiments of Millikan have shown that there is photoelectric current even for frequencies below the threshold, contrary to the accepted explanation by Einstein. In fact, the original experimental data of Millikan show an asymptotic behavior of the (current) vs (voltage) curves along the energy axis with no clear 'threshold frequency'. The photoelectric equations **(9)** and **(10)** we derived above agree with these experimental anomalies, however.

In an article Richard Keesing of York University, UK , states,

> *I noticed that a reverse photo-current existed … and try as I might I could not get rid of it.*
> …
> *My first disquieting observation with the new tube was that the **I/V** curves had high energy tails on them and always approached the voltage axis asymptotically. I had been brought up to believe that the current would show a well defined cut off, however my curves just refused to do so.*
> …
> *Several years later I was demonstrating in our first year lab here and found that the apparatus we had for measuring Planck's constant had similar problems.*
> …
> *After considerable soul searching it suddenly occurred on me that there was something wrong with the theory of the photoelectric effect …*

In the same article, taking the original experimental data from the 1916 experiments by Millikan, Prof. Keesing plots the following graphs.

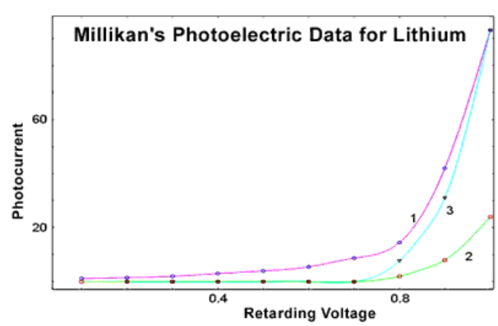


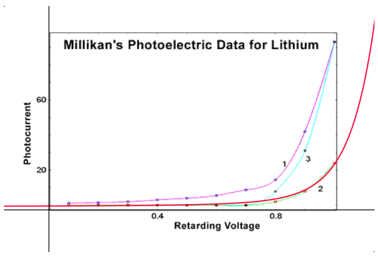
figure 1

In what follows, we analyze the asymptotic behavior of equation **(10)** by using a function of the same form as **(10)**.

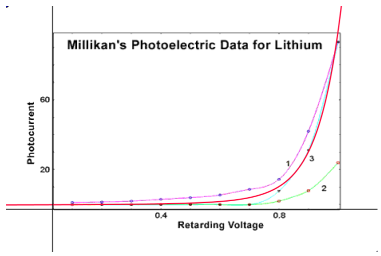
$$f(x) = \frac{A\left(e^{b(x-c)} - 1\right)}{x - c} + d \tag{12}$$

Note: We use d since some graphs typically are shifted up a little for clarity.

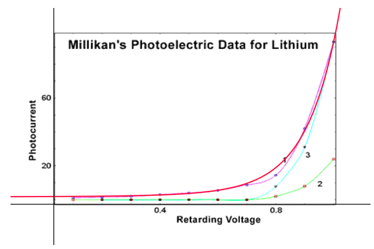
The following graphs match the above experimental data to various graphs (in red) of equation **(12)**



A=0.13 b=1.98 c=5.95 d=0,07
figure 2



A=0.09 b=2.07 c=4.88 d=0.09
figure 3



A=0.05 b=1.41 c=3.04 d=0.18
figure 4

The above graphs seem to suggest that Eq. **(10)** agrees well with the experimental data showing the asymptotic behavior of the (current) v (energy) curves. But this consideration is only preliminary and invites a more systematic experimental exploration of these ideas and explanation of The Photoelectric Effect.

Conclusion:

The same ideas and mathematical derivations used to demonstrate in another paper that *Planck's Law is an exact mathematical identity* provided in this paper a non-photon explanation of The Photoelectric Effect. Furthermore, we are able to derive a formula for the photoelectric current in terms of the intensity and frequency of radiation that fits the experimental characteristics of the Photoelectric Effect well, including the asymptotic behavior of the (current) v. (energy) curves. This short paper, however, can only serve as an invitation for further research and study by groups with the facilities and resources to make such experiments.

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