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Reformulation of the Einstein's Photoelectric Equation on the Basis of the Newly Emerged Quantum Concepts

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Abstract Startling findings concerning the Planck‟s quantum equation, E = hv, have been brought to light in this work. It has been conclusively proven that the conceptual correctness of this quantum equation cannot be justified by any physical reasoning, and that there have emerged a newly formulated but promising quantum equation, P = bv, which relates the power „P‟ of a quantum oscillator, such as a photon, with its frequency „v‟ (where 'b'is the elementary quantum of energy observable in nature), to be the right kind of quantum equation. Since the core concept in the Einstein‟s theory of the photoelectric effect is critically dependent on the correctness of the Planck‟s quantum equation, bringing about an appropriate modification in the Einstein‟s derivation of the photoelectric effect has been deemed essential. Reformulation of the Einstein‟s photoelectric equation has been carried out in this work taking into consideration the newly emerged quantum perspective as well as the concept of energy-power dichotomy that photons and photoelectrons do exhibit. Thus, the Einstein‟s photoelectric equation expressed in all energy terms, Ee = hv h v0, is get converted into all power terms, Pe = bv bv0. This modified form of the Einstein‟s photoelectric equation has been found to be capable of providing satisfactory explanation to all the salient features the photoelectric effect exhibits.

Keywords: *Einstein‟s photoelectric equation (EPE), reformulation of EPE, new quantum perspective, energy-power dichotomy, photons and photoelectrons*

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1. Introduction

Photoelectric effect is a phenomenon of fundamental significance in the development of modern physics because of the puzzling question it raised about the nature of light, compelling the physicists to think about the corpuscular aspect of light. It is a phenomenon of emission of electrons from a metal surface when it is illuminated with light having frequencies greater than that of a certain minimum frequency specific to the metal. Photoelectric effect is well known to exhibit the following salient features. The kinetic energy of the emitted electrons depends on the frequency v of the incident light, not its intensity; for a given metal, there is a threshold frequency v_0, below which no electrons are emitted, and that the emission of electrons takes place almost instantaneously.

In 1905 Einstein [1] extended the Planck‟s quantum hypothesis for evaluating the energy quantum of light. To explain the photoelectric effect Einstein introduced the idea that light itself is made of discrete units of energy, called photons. He also assumed that an electron on the surface of a metal absorbs either the whole of a photon or nothing. Furthermore, he also assumed that the part of the energy of the photon is expended to liberate the electron, which requires a fixed energy W, known as the work-function of the metal, the rest is converted into the kinetic energy ½ $m_e v^2$ of the emitted electron (where m_e is the mass of the electron and v is its velocity). Einstein presumed W of a metal to be equivalent to the energy, hv_0, corresponding to the threshold light frequency v_0. All these theoretical consideration led Einstein to deduce his famous photoelectric equation as :

$$E_k = hv - W \qquad \text{or,} \qquad E_k = hv - hv_0 \qquad (1)$$

where, E_k is the kinetic energy of the photoelectrons.

This simple and elegant equation due to Einstein is capable of providing satisfactory explanation to all the characteristic features the photoelectric effect exhibit.

However, there do exists good reasons which compel us to rethink and reformulate the Einstein‟s photoelectric equation. In fact the findings of some of the recent studies [2,3,4,5] have proved themselves to be too compelling to be ignored. While the Einstein‟s core theoretical concepts of his theory of photoelectric effect critically relied the assumed correctness of the Planck‟s quantum equation, E = hv, the authors of these studies have adduced convincing evidences to prove this equation to be not conceptually the right kind of quantum equation. Amongst them the findings of the study [2] deserves special attention.

This study has conclusively proven the Planck‟s black-body (BB) radiation formula to be fallacious on several counts. The root cause of the flaws and dimensional discrepancies that the Planck‟s BB radiation theory suffers from has been shown to be the Plank's fundamental quantum equation E = h*v*, which is being based on conceptually faulty hypothesis — the energy of a harmonic oscillator to be directly proportional to its oscillation frequency, — cannot be justified by any physical reasoning. Since frequency is purely a temporal concept and totally unrelated to anything attributable to be the energy content of the BB radiation or the oscillators within the BB cavity. Moreover, this assumption is directly in contradiction with the well-established physical concept — the energy of a harmonic oscillators should be directly proportional to the square of its amplitude of oscillation. It has also been revealed in that study that although the dimensional analysis of the Planck‟s constant h should possess a dimension of that of energy, Plank had mistakenly given it a dimension of that of an action. A noteworthy finding of this study is the formulation of a new quantum equation which relates the power P‟ of a quantum oscillator with its oscillation frequency, *v*:

$$P = bv \qquad (2)$$

where, b‟ is the elementary quantum of energy observable in nature. A justification for the physical concept that it is the power P of a quantum oscillator which could be directly proportional to its oscillation frequency comes from the findings of the works of Ghoshal and Kole [6] where these authors have proven this relationship. And a conclusive proof of the correctness of Eq (2) comes from the fact that when h is replaced by b‟ in the Planck‟s BB radiation formula it becomes absolutely free from all the flaws and dimensional discrepancies.

That it is also possible to deduced this newly formulated quantum equation P = b*v* should we take into account a simple and realistic consideration following the works of Brooks [3], Worsely [4] and Morentenson [5]. These authors argued that there should exists an elementary quantum of energy in nature, not the elementary quantum of action, h. Instead of taking into account all the *v* number of complete oscillations in a time period of one second that an electromagnetic wave executes (which) the Planck‟s equation E = h*v* implies for the determination of energy quantum of an oscillator) then took into consideration the energy element ∊

Corresponding to a single cycle of oscillation of an electromagnetic radiation. According to these authors the elementary particles of light or photons are the single cycle oscillation of light, and that all photons, irrespective of their oscillation frequencies, possess the same energy, i.e., 6.626 x 10^{34} J, which these authors have identified as the elementary quantum of energy. Thus, in accordance with these authors the Plank's quantum equation takes the from

$$E = \epsilon v \qquad (3)$$

The dimensional discrepancy that this equation suffers from (while the left hand side of this equation possesses a unit of energy, the dimension of the right hand side corresponds to that of a power) could, however, be rectified simply by assuming that it is the power P that a photon possesses which is directly proportional to its oscillation frequency *v*. A justification for such a supposition comes from the fact that for any single cycle oscillation of light of frequency *v* there is associated a corresponding time period τ for the oscillation so that the power P that a photon of frequency *v* would possess will be given as ∊/τ and that, 1/τ = *v*. Thus, we arrive at the same new form of the Planck‟s quantum equation as that has already been mentioned, that is : P=b*v*.

The Planck‟s action constant h also, thereby, gets a new meaning : an elementary quantum of energy observable in nature. It may be noted in this context that although the photons of all wavelengths of light possess the same quantum of energy, the power possessed by a photon (being determined by the time period of its oscillation, and hence, determined by it s oscillation frequency) would vary widely depending upon the wavelength of light the photon corresponds to.

In view of the aforementioned newly emerged quantum concepts reformulation of the Einstein‟s photoelectric equation in accordance with the new quantum perspective was deemed essential. Efforts have been directed in this work to achieve this objective.

2. Energy-Power Dichotomy of Photons and Photoelectrons

In what follows it will be seen that, in addition to their respective wave-particle duality, both photons as well as photoelectrons do exhibit the phenomenon of energy-power dichotomy, that is, both possessing at the same time a quantum of energy and a quantum of power as well.

Quantum physicists envisage a photon as a particle-like discrete quantum of energy of elecetromagnetic radiation in which there occurs a very rapid oscillations of the coupled electric and magnetic fields as the photon propagates. According to the wave nature of light it is the square of the electric field amplidue which is attributed to be the source of energy content of a photon. However, because of the undumlatory nature of both the electric and magnetic fields, the electric field amplitude undergoes a variation from its maximum to zero and back to maximum in each cycle of oscillations, giving rise to the corresponding energy variation. This energy variation manifested into the corresponding variation of the magnetic field. The time rate of change of the electric field and, consequently, its transformation into magnetic field within a photon could be thought of as the photon to be possessing a quantum of power. Since larger the oscillation frequency of the photon faster will be the rate with which electric field amplitude within the photon will be undergoing variation, greater will be the power P‟ of the photon. In other words, the power P that a photon possess will be directly proportional to the frequency ν with which it is oscillating , and therefore , can be expressed as P= b *v*.

We have already come across such a relationship in the case of quantum oscillators [2].

An analysis of the intricacies involved in the dynamics of the photoelectrons helped us to decipher that, similar to those of the photons, photoelectrons also do exhibit energy-power dichotomy. A standard experimental procedure for the determination of the kinetic energy of the photoelectrons for a given frequency of the incident light consists of adjusting the electrostatic potential between the plate emitting the photoelectrons and the collector plate, so as to established a stopping potential. The retarding potential at which the photoelectric current becomes zero is called the stopping potential. If V be the stopping potential, the work done by the retarding potential in stopping a photoelectron will be eV, where e is the electronic charge. Thus we have:

$$eV = E_k \qquad (4)$$

Or, in other words, the kinetic energy of the photoelectron has transformed into a potential energy eV in the electro-retarding potential system. However, there involves a temporal concept in this dynamics of photoelectrons. The time rate of transformation of the kinetic energy of a photoelectron into its potential energy is determined by the traverse time of the photoelectron between the two electrodes. If τ be such a time period, the time rate of change of kinetic energy of the photoelectron (or, the rate of work done by the photoelectron), i.e., the power possessed by the photoelectron, P_e, will be :

$$P_e = eV/\tau \quad \text{or,} \quad P_e = I_e V \qquad (5)$$

Where I_e is the tiny current due to the flow of a single electron between the electrodes. It is conceivable, therefore, that greater are frequency of the incident light the larger will be kinetic energy as well as the power possessed by the ejected photoelectron. It may be concluded, therefore, that it is not only the photons but also the photoelectrons which exhibit the phenomenon of energy-power dichotomy and that the power that a photoelectron would possess is proportional to the frequency of the light causing it to get emitted. In fact energy-power dichotomy could in general be observed in any mechanical system where the energy and power are so intimately related to each other that we cannot think one without the other, or do away with one of them.

Thus, in addition to their respective wave-particle duality, both the photons and the photoelectrons do exhibit the phenomenon of energy-power dichotomy, that is, both possessing at the same time a quantum of energy and a quantum of power as well.

3. Result and Discussions

3.1 Reformulation of the Einstein's Photoelectric Equation

According to the Einstein‟s theory of photoelectric effect a photoelectron needs an amount of energy $h\nu_0$ corresponding to the frequency ν_0 in order to overcome the work function of the metal which it acquires from the incident photon. However, in accordance with the newly formulated power-frequency quantum equation the frequency ν_0 corresponds to a threshold quantum of power, $b\nu_0$. Thus, when all the energy quantum terms of the Einstein‟s photoelectric equation is expressed as the corresponding power quantum terms the Einstein‟s equation take the form :

$$P_e = b\nu - b\nu_0 \qquad (6)$$

Two of the newly emerged perspectives – the newly formulated quantum equation which relates the power of a quantum oscillator with its frequency and the phenomenon of energy-power dichotomy exhibited by both photons and photoelectrons – have proved to be useful in bringing about a simple modification in the Einstein‟s photoelectric equation. A comparison of the photoelectric equation re-casted form of the Einstein‟s equation (Eq.6) with that of the Einstein‟s original photoelectric equation (Eq.2) tells us that except for a paradigm shift from all energy terms to all power terms the expressions for both the equations are composed of identical mathematical structure, since both of these equations are deduced on the basis of the same theoretical ideas. It is expected, therefore, that analogous to that of the Einstein‟s equation salient aspects of the photoelectric effect will also find an easy explanation in terms of Eq. 6 should we follow the Einstein‟s way of interpretation taking into account the quantum of power that the incident photons and the photoelectrons posses. When a photon possessing a quantum of power $b\nu$ strikes an electron on a metal surface the incident photon transfers all its energy to the electron. Having acquired sufficient power the electron is get ejected from the metal with a power which is equal to the power of the incident photon minus the power a photoelectron has to expend in order to escape from the metal surface. The power with a photoelectron is get ejected from the metal surface is manifested as its kinetic energy which is in accordance with the principle of energy-power dichotomy.

Equipped with the novel concept that all photons possess the smallest possible quantum of electromagnetic energy b‟ but they differ widely in respect to their power P, which is determined by their single-cycle oscillation time period τ, enables us to find a satisfactory explanation to an important aspect of the photoelectric effect ─ the almost instantaneous emission of the photoelectrons. This phenomenon arises since each photons incident on a metal surface are capable of transferring all their energy to the electrons they are interacting with in a very short period of time determined by their τ (which are generally of the order of 10^{14} ─ 10^{15} seconds for the visible light), and hence, the observed phenomenon.

4. Conclusions

In v̅iew of the Planck‟s quantum equation, $E = h\nu$, conclusively proven to be n incorrect quantum equation, bringing about an appropriate modification in the conceptual foundation of the Einstein‟s derivation of the photoelectric equation was deemed essential. To meet this objective we are guided by the newly emerged quantum concept in that it is the quantum of power of a harmonic oscillator which is directly proportional to its frequency. The concept of energy-power dichotomy that both photons and photoelectrons do exhibit has also been proved helpful in reformulating the photoelectric equation. The newly formulated photoelectric equation expressed in all power terms is capable of providing an easy explanation to all the features the photoelectric effect exhibits. In conclusion, efforts have been directed in this work to place the theoretical interpretation of the photoelectric effet on sound conceptual foundation.

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