A New Approach on the Photoelectric Effect
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When photons hit a material surface they exert a pressure on it. It was shown that this pressure has a negative component (opposite to the direction of propagation of the photons) due to the existence of the negative linear momentum transported by the photons. Here we show that, in the photoelectric effect, the electrons are ejected by the action of this negative component of the momentum transported by the light photons. It is still shown that, also the gravitational interaction results from the action of this negative component of the momentum transported by specific photons.

Key words: Photoelectric effect, Photoelectrons, Radiation Pressure, Gravitational Interaction.

1. Introduction

Besides energy the photons transport linear momentum. Thus, when they hit a surface, they exert a pressure on it. Maxwell showed that, if the energy \( U \) of the photons is totally absorbed by the surface during a time \( t \), then the total momentum \( q \) transferred to the surface is \( q = U/\nu \), where \( \nu \) is the velocity of the photons \([1]\). Then, a pressure, \( p \) (defined as force \( F \) per unit area \( A \) ), is exerted on the surface.

In a previous paper \([2]\), we have shown that this pressure has a negative component (opposite to the direction of propagation of the photons) due to the existence of the negative linear momentum transported by the photons, shown in the new expression for momentum \( q \) transported by the photon, i.e.,

\[
\tilde{q} = \frac{U}{\nu} = \frac{hf}{\nu} - \frac{1}{2} \frac{hf_0}{\nu} = \left(1 - \frac{1}{2} \frac{f_0}{f} \right) \frac{hf}{c} \tilde{n},
\]

where \( f \) is the frequency of the photon and \( f_0 \) is a limit-frequency, which should be of the order of \( 10 \text{Hz} \) or less; \( n_r = c/\nu \) is the index of refraction of the mean.

Equation above shows that for \( f > f_0/2 \) the resultant momentum transported by the photon is positive, i.e., if this momentum is absorbed by a surface, pressure is exerted on the surface, in the same direction of propagation of the photon. These photons are well-known. However, Eq. (1) point to a new type of photons when \( f = f_0/2 \). In this case \( q = 0 \), i.e., this type of photon does not exert pressure when it incides on a surface. What means that it does not interact with the matter. Obviously, this corresponds to a special type of photon, which we will call of neutral photon. Finally, if \( f < f_0/2 \) the resultant momentum transported by the photon is negative. If this momentum is absorbed by a surface, pressure is exerted on the surface, in the opposite direction of propagation of the photon. This special type of photon has been denominated of attractive photon.

Here we show that, in the photoelectric effect, the electrons are ejected by the action of the negative component of the momentum transported by the light photons. It is still shown that, also the gravitational interaction results from the action of the negative component of the momentum transported by specific photons.

2. Theory

The photoelectric effect was first observed in 1887 by Heinrich Hertz \([3,4]\) during experiments with a spark-gap generator — the earliest form of radio receiver. He discovered that electrodes illuminated with ultraviolet light create electric sparks more easily.

Attempts to explain the effect by Classical Electrodynamics failed. In 1905 Einstein proposed that the experimental data from the photoelectric effect were the result of the fact of light energy to be carried in discrete quantized packets.

When a photon strikes on an electron the momentum carried by the photon is transferred to the electron. According to Eq. (1), the momentum transferred to the electron is given by

\[
\tilde{q} = \frac{U}{\nu} = \frac{hf}{\nu} - \frac{1}{2} \frac{hf_0}{\nu} = \left(1 - \frac{1}{2} \frac{f_0}{f} \right) \frac{hf}{c} \tilde{n},
\]
\[ \tilde{q} = \left(1 - \frac{1}{2} \frac{f_0}{f} \right) \left( \frac{h}{c} \right) \left( \frac{c}{v} \right) = \frac{h}{\nu} - \frac{hf_0}{2 \nu} = \tilde{q}_r - \tilde{q}_a \quad (2) \]

where \( \tilde{q}_r = \tilde{F}_r \Delta t_r \) and \( \tilde{q}_a = \tilde{F}_a \Delta t_a \). Thus, the electron requires a time interval \( \Delta t_r \) for absorbing a quantum of energy \( hf \) and a time interval \( \Delta t_a \) for absorbing a quantum of energy \( hf_0 \).

Assuming that the time interval required by the photon for absorbing a quantum of energy \( hf \) is proportional to the power of the photon \( \left( hf^2 \right) \), i.e., \( \Delta t_r \propto hf^2 \) and \( \Delta t_a \propto hf_0^2 \). Then, we get

\[ \frac{\Delta t_r}{\Delta t_a} = \frac{f^2}{f_0^2} \quad (3) \]

Since the expressions of \( \tilde{F}_r \) and \( \tilde{F}_a \) are given, respectively, by \( \tilde{F}_r = \tilde{q}_r / \Delta t_r = hf / \nu \Delta t_r \) and \( \tilde{F}_a = \tilde{q}_a / \Delta t_a = hf_0 / 2 \nu \Delta t_a \), then, we obtain

\[ \frac{F_a}{F_r} = \frac{1}{2} \left( \frac{\Delta t_r}{\Delta t_a} \right) \frac{f_0}{f} \quad (4) \]

Substitution of Eq. (3) into Eq. (4) gives

\[ \frac{F_a}{F_r} = \frac{1}{2} \frac{f}{f_0} \quad (5) \]

This equation shows that the force \( \tilde{F}_a \) is directly proportional to the frequency \( f \) of the photon, and thus explains why low frequency light does not produce photoelectrons. If the light incident on the electron has low frequency, then the force \( \tilde{F}_a \) may not be strong enough to eject the electron (whatever the intensity of the light beam). Thus, in order to produce the photoelectric effect the light incident must have high frequency (upper spectrum of light).

In the case of the photoelectric effect we have \( f >> f_0 \), then \( F_a >> F_r \). Thus, the resultant acting on the electron is

\[ \tilde{F}_r - \tilde{F}_a \approx -\tilde{F}_a \]. Then, the condition for an electron be ejected from a metallic surface is

\[ \left| \tilde{F}_r - \tilde{F}_a \right| r_e \approx |\tilde{F}_a r_e| = \varphi \quad (6) \]

where \( r_e \) is the orbital radius of the electron and \( \varphi \) is the work function, which gives the minimum energy required to remove a delocalized electron from the surface of the metal.

Substitution of the expression of \( \tilde{F}_a \) into Eq. (6) yields

\[ \Delta t_a = \frac{r_e hf_0}{2 \nu \varphi} \quad (7) \]

Substitution of the expression of \( \Delta t_a \), given by Eq. (3), into Eq. (7), gives

\[ \Delta t_r = \frac{hf^2 r_e}{2 \nu f_0 \varphi} \quad (8) \]

For example, in the case of a light beam \( f = 4.39 \times 10^{14} \text{ Hz}; \nu \approx c \), incident on a lamina of Sodium metal \( r_e = 9.3 \times 10^{-11} \text{ m} \) and \( \varphi = 2.75 \text{ eV} = 4.4 \times 10^{-19} \text{ J} \) [5], considering \( f_0 \approx 10 \text{ Hz} \) [2], then Eqs. (7) and (8) give

\[ \Delta t_a \approx 10^{-33} \text{ s} \quad (9) \]
\[ \Delta t_r \approx 10^{-6} \text{ s} \quad (10) \]

Thus, we can conclude that the electron is ejected by the action of the force \( \tilde{F}_a \) much before the total absorption of the quantum \( hf \). Therefore, the cause of the ejection of the electron is not the absorption of the quantum \( hf \) (as Einstein thought [6]), but the action of the force \( \tilde{F}_a \) (See Fig.1). Similarly, when an electron is pumped from an orbit to another - by the action of a light photon, it is ejected from its initial orbit by the force \( \tilde{F}_a \).

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1 The work function of very pure Na is 2.75 eV. The work function of not purified sodium is less than 2.75 eV because of adsorbed sulfur and other substances derived from atmospheric gases. The most common values cited in the literature are 2.28 eV and 1.82 eV.
Then, in its trajectory, the electron is “captured” in the upper energetic level $E_f$. Therefore, the electron will be pumped from the initial orbit to a final orbit if $hf - \frac{1}{2}hf_0 = E_i - E_f$, where $E_i$ is the initial energy in the initial orbit, $E_f$ is the total energy in the final orbit.

Finally, we will derive the new expression for the pressure exerted by a radiation on a surface. From Eq. (2), we have $\dot{q} = \dot{q}_r - \dot{q}_a$. Thus, we can write that

\[
\frac{\dot{q}}{\Delta t} = \frac{\dot{q}_r - \dot{q}_a}{\Delta t} \Rightarrow F = \frac{h}{v_0} - \frac{hf_0}{2v_0} = \left(1 - \frac{f_0}{2f}\right)\frac{hf}{v_0}
\]

Therefore,

\[
F_{\text{total}} = \left(1 - \frac{f_0}{2f}\right)NHF = \left(1 - \frac{f_0}{2f}\right)\frac{P}{v} \quad (11)
\]

where $N$ is the total number of absorbed photons by the surface; $P$ is the total power. Thus, the expression of the pressure, $p$, exerted by the radiation on a surface with area $A$ is given by

\[
p = \frac{F_{\text{total}}}{A} = \left(1 - \frac{f_0}{2f}\right)\frac{P}{A} = \left(1 - \frac{f_0}{2f}\right)\frac{D}{v} \quad (12)
\]

where $D$ is the power density of the radiation. Note that, only for $f >> f_0$ the equation above reduces to $p \approx D/v$ (the well-known expression for radiation pressure).

The law of inverse square of the distance, which is implicit in the Newton’s law, shows that gravitation is propagated spherically. This reveals the principle of diffusion of the gravitational energy, i.e., it is transmitted by waves (or photons). The Quantum Field Theory shows that the gravitational interaction results from the interchange of a type of “virtual” quantum. Then, based on the above exposed, we can conclude that this typical “virtual” quantum is a typical “virtual” photon. Thus, we can say that the gravitational interaction, between two particles with gravitational masses $m_{g1}$ and $m_{g2}$, respectively, results from the action of an amount of energy related to $E_{g1} = m_{g1}c^2$, ejected from the particle 1 under the form of $N_1$ “virtual” photons with a typical frequency $f_{g1}$, and an amount of energy related to $E_{g2} = m_{g2}c^2$, ejected from the particle 2 under the form of $N_2$ “virtual” photons with frequency $f_{g2}$.

Assuming that the amounts of energies ejected from the particles 1 and 2 are, respectively, $k_0E_{g1}$ and $k_0E_{g2}$, where $k_0$ is a constant, and considering that, according to Eq. (1), the energy of the photons is expressed by $hf - \frac{1}{2}hf_0$, then we can write that

\[
k_0E_{g1} = N_1\left(hf_1 - \frac{1}{2}f_0\right) \quad (13)
\]
\[ k_0 E_{g1} = N_2 (\hbar f_g - \frac{1}{2} f_0) \]  

(14)

Since

\[ \left( \frac{A_1}{A_1} \right) k_0 E_{g1} = A_1 k_0 \left( \frac{E_{g1}}{A_1} \right) = k_{s1} \left( \frac{E_{g1}}{A_1} \right) \]

and

\[ \left( \frac{A_2}{A_2} \right) k_0 E_{g2} = A_2 k_0 \left( \frac{E_{g2}}{A_2} \right) = k_{s2} \left( \frac{E_{g2}}{A_2} \right) \]

Then, Eqs. (13) and (14) can be rewritten as follows

\[ k_{s1} \left( \frac{E_{g1}}{A_1} \right) = N_1 (\hbar f_g - \frac{1}{2} f_0) \]  

(15)

and

\[ k_{s2} \left( \frac{E_{g2}}{A_2} \right) = N_2 (\hbar f_g - \frac{1}{2} f_0) \]  

(16)

where \( A_1 \) and \( A_2 \) are the incidence areas of the mentioned “virtual” photons, respectively on the particles 1 and 2 (See Fig.2); \( k_{s1} = k_0 A_1 \) and \( k_{s2} = k_0 A_2 \).

If the forms and the gravitational masses of the two particles remain constants, then \( E_{g1} / A_1 \) and \( E_{g2} / A_2 \) are constants, i.e.,

\[ \frac{E_{g1}}{A_1} = k_1 \]  

(17)

and

\[ \frac{E_{g2}}{A_2} = k_2 \]  

(18)

where \( k_1 \) and \( k_2 \) are constants.

From Eq. (17) and (18), we obtain

\[ E_{g1} E_{g2} = k_1 k_2 A_1 A_2 \]  

(19)

By substitution of \( E_{g2} \) given by Eq. (14) into Eq. (19), gives

\[ E_{g1} = \frac{k_0 k_1 k_2 A_1 A_2}{N_2 (\hbar f_g - \frac{1}{2} f_0)} \]  

(20)

Since \( N_1 \) and \( N_2 \) are pure numbers, then \( k_0 k_1 k_2 A_1 A_2 / N_2 \) is a constant, which here will be denoted by \( K \).

On the other hand, we can write that

\[ \frac{k_0 E_{g2}}{S_2} A_1 = n_1 (\hbar f_g - \frac{1}{2} f_0) \]  

(21)

where \( n_1 \) is the number of photons incident on particle 1 and \( S_2 = 4\pi r_2^2 \), where \( r_2 \) is the distance from the center of the particle 2 to the center of the particle 1.

Substitution of \( (\hbar f_g - \frac{1}{2} f_0) \) given by Eq. (20) into Eq. (21), gives

\[ n_1 = \left( \frac{k_{s1}}{K} \right) \frac{E_{g1} E_{g2}}{S_2} = \left( \frac{1}{\alpha^2} \right) \frac{E_{g1} E_{g2}}{S_2} \]  

(22)

The constant \( K/k_{s1} \) has the dimension of \((\text{force})^2\). Thus, \( k_{s1}/K \) was changed in Eq. (22) by the constant \( 1/\alpha^2 \), where
\[ \alpha_1^2 = \frac{K}{k_1} = \frac{K}{k_0} \frac{k_0 k_1 A_1 A_2}{N_2 k_0 A_1} = \frac{k_1 k_2 A_2}{N_2} \]

or

\[ \alpha_1^2 = \frac{k_1 k_2 A_2}{N_2} = \left( \frac{E_{g_2}}{A_2} \right) \frac{k_1 A_2}{N_2} = \frac{k_1 E_{g_2}}{N_2} \]  

Substitution of \( N_2 \) gives by Eq. (16) into Eq. (23), yields

\[ \alpha_1^2 = E_{g_2} \left( \frac{hf_g - \frac{1}{2} hf_0}{k_0 E_{g_2}} \right) = \frac{k_1 (hf_g - \frac{1}{2} hf_0)}{k_0} \]  

(24)

Note in the equation above that the frequency \( f_g \) of the “virtual” photon (quantum of the gravitational interaction) is in fact constant, because \( \alpha_1, k_0, f_0 \) and \( k_1 \) are constants. This confirms our initial hypotheses that the quantum of the gravitational interaction, is a photon with a typical frequency.

By analogy to Eq. (22), we can write that

\[ n_2 = \left( \frac{k_{s_2}}{K} \right) \frac{E_{g_1} E_{g_2}}{S_1} = \left( \frac{1}{\alpha_2^2} \right) \frac{E_{g_1} E_{g_2}}{S_1} \]  

(25)

Multiplying \( n_1 \) (Eq. 22) by \( n_2 \) (Eq. 25), we obtain

\[ n_1 n_2 = \frac{1}{\left( \alpha_1 \alpha_2 \right)^2} \frac{E_{g_1} E_{g_2}}{S_1 S_2} = \frac{c^8 m_1^2 m_2^2}{\left( \alpha_1 \alpha_2 \right)^2 \left( 4 \pi r_1^2 \right) \left( 4 \pi r_2^2 \right)} \]  

(26)

where \( S_1 = 4 \pi r_1^2 \); \( r_1 \) is the distance from the center of the particle 1 to the center of the particle 2. Since \( r_1 = r_2 = r \), then Eq. (26) can be rewritten in the following form:

\[ n_1 n_2 = \frac{c^8 m_1^2 m_2^2}{\left( \alpha_1 \alpha_2 \right)^2 \left( 4 \pi r^2 \right)^2} \]  

(27)

According to Eq. (11), we can write that

\[ F_1 = \left( 1 - \frac{f_0}{2 f_g} \right) \frac{n_1 hf_g}{e \Delta t_1} \]  

(28)

and

\[ F_2 = \left( 1 - \frac{f_0}{2 f_g} \right) \frac{n_2 hf_g}{e \Delta t_2} \]  

(29)

whence we obtain

\[ F_1 F_2 = \left( 1 - \frac{f_0}{2 f_g} \right)^2 \frac{n_1 n_2 (hf_g)^2}{c^2 \Delta t_1 \Delta t_2} \]  

(30)

Substitution of \( n_1 n_2 \) given by Eq. (26) into Eq. (30), yields

\[ F_1 F_2 = \left( 1 - \frac{f_0}{2 f_g} \right)^2 \frac{(hf_g)^2 c^6 m_1^2 m_2^2}{\Delta t_1 \Delta t_2 \left( \alpha_1 \alpha_2 \right)^2 \left( 4 \pi r^2 \right)^2} \]  

(31)

For \( \Delta t_1 = \Delta t_2 = \Delta t_g \), we have \( F_1 = F_2 = F \). Thus, Eq. (31) reduces to

\[ F = \left( 1 - \frac{f_0}{2 f_g} \right) \frac{c^3 (hf_g) m_1 m_2}{4 \pi \Delta t_g \left( \alpha_1 \alpha_2 \right)^2 r^2} \]  

(32)

In order to communicate ultra-small gravitational forces the energy \( hf_g - \frac{1}{2} hf_0 \) of the “virtual” photon (quantum of the gravitational interaction) must be also ultrasmall. This means that, \( f_g \) must be less than \( \frac{1}{2} f_0 \) and ultra close to \( \frac{1}{2} f_0 \), i.e.,

\[ hf_g - \frac{1}{2} hf_0 = -\varepsilon \rightarrow 1 - f_0/2 f_g = -\varepsilon/hf_g \text{, where } \varepsilon \text{ is a constant. Thus, Eq. (32) can be rewritten as follows} \]

\[ F = \frac{\varepsilon c^3 m_1 m_2}{4 \pi \Delta t_g \alpha_1 \alpha_2 r^2} \]  

(33)

The term in parentheses must generate, obviously, the universal gravitational constant, \( G = 6.67 \times 10^{-11} N (m/kg)^2 \), i.e.,

\[ \frac{\varepsilon c^3}{4 \pi \Delta t_g \alpha_1 \alpha_2} = G \]  

(34)
For \( \Delta_{t1} = \Delta_{t2} = \Delta_{tg} \) and \( m_1 = m_2 = 1 \) (just one “virtual” photon incident on each particle) Eq. (30) gives \( F_1 = F_2 = F_{\text{min}} \), where \( F_{\text{min}} \) is the minimal gravitational force in the Universe, i.e.,

\[
F_{\text{min}} = \left(1 - \frac{f_0}{2f_g}\right) \frac{h f_g}{c M_g} = -\frac{\varepsilon}{c M_g} \quad (35)
\]

On the other hand, according to the Newton’s law, we can write that

\[
F_{\text{min}} = -G \frac{m_{g_{\text{min}}}^2}{r_{\text{max}}^2} = -\frac{\varepsilon}{c M_g} \quad (36)
\]

where \( m_{g_{\text{min}}} \) is the gravitational mass of the material particle with minimal mass in the Universe, and \( r_{\text{max}} \) is the maximal distance (diameter of the Universe) between two particles of this type.

Substitution of this value into Eq. (36), and considering that \( m_{g_{\text{min}}} \ll m_{\text{proton}} \) and \( r_{\text{max}} \gg 2c/H_0 \) (diameter of the observable Universe) where \( H_0 = 1.75 \times 10^{-18} \text{s}^{-1} \) is the Hubble constant, then we can conclude that, \( \varepsilon \) must be ultra-small.

Based on Eq. (3), we can write that

\[
\frac{\Delta_{\mu}}{\Delta_{g}} = \frac{f_0^2}{f_g^2} \quad (37)
\]

Since \( \Delta_{\mu} \approx 10^{-33} \text{s} \) (Eq. (9)), and as \( f_g \ll f_0/2 \), then Eq. (37) gives

\[
\Delta_{g} \approx 10^{-33} \text{s} \quad (38)
\]
References


