Classical justification of the photoelectric effect

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Abstract

It is said that empirical results of the photoelectric effect have no classical justification and then are used for deduction of the famous relation $E = h\nu$ as an alternative way to Planck's deduction. We show that these results are in fact justifiable by the classical theory of electromagnetism and then this way can not be a valid manner for obtaining this relation. Using the presented discussions simple justification of the Rayleigh scattering and of the action mechanism of laser are presented in support of the validity of the discussion.

1 Introduction

As we know the origin of the quantum physics was Planck's deduction of the famous relation $E = h\nu$. Since this deduction is done by using some mathematical relations and the statistical mechanics (that we have proceeded to it in the 11th article of the book where invalidity of this deduction has been proven quite mathematically and in detail), it isn't inserted in many of the elementary textbooks of modern physics or quantum physics, instead they proceed to draw this relation from the photoelectric effect relying on this deduction that the classical physics is not able to justify the empirical results of this effect, and then the only justification is one that results in the relation $E = h\nu$. The object of this article is to show that this is not the case that the classical physics cannot justify the empirical results of the photoelectric effect, and in fact it is able to justify these results well. In support of the discussion presented for classical justification of the results of the photoelectric effect, we shall apply results of the discussion to justification of the Rayleigh scattering and of the real action of laser.

2 Electromagnetic classical theory and justification of the results

Important empirical results of the photoelectric effect can be categorized as follows:

(a). If an electromagnetic beam is able to release electron from the metal surface, its intensity will be proportional to the electron current arising from the released electrons.

(b). A monochromatic beam is not able to release electron even though its intensity is increased arbitrarily, unless its frequency has a definite minimum magnitude. This magnitude depends on the kind of the metal.

(c). The curve of the kinetic energy of the released electron against the frequency of the monochromatic beam releasing electron, is a straight line which its slope is the same for all the metals.

We know that an electromagnetic wave consists of electric and magnetic fields normal to each other which are alternated in time and space. Let's see what an electromagnetic beam, descending on some metal surface causing emission of electron from it, consists of. Since inevitably the beam occupies some volume and on its cross-section surface on the metal there are numerous valence electrons, we conclude that the beam, as shown in Fig. 1, is in fact consisting of some discrete waves each of which aiming at an electron. The intensity of the beam is in fact a demonstration of the vector sum of the amplitudes of these waves of the beam. In this manner the case (a) is justified easily: the more the number of these waves each of which being able to release an electron, the more the released electrons.

Now consider two of these waves: the first one (A in Fig. 2) with a frequency sufficiently low such that it is not able to release electron, and the second one (B in Fig. 2) with a frequency sufficiently high such that it is able to release electron. We want to find the cause of this matter. This "cause" must be searched in the impulsive force that the second one, with its great frequency can exert on the electrons of the metal, while it is natural that the first one in a longer time interval exerts some more still force on the electrons which although causes some disorders and weakening of them these are not so strong and sudden that cause freedom of the electrons, but the momentum will be exerted on the whole atom chiefly and causes producing of some heat which arises from the movement of the atoms. We can imagine this impulsive force proportional to the absolute value of the slope of the wave.

In fact this is a mechanical case that an intensive impulse in which some definite momentum is transferred in a short time causes locally disconnecting of the structural bonds (ie molecular bonds) of the body under impulse; while a still impulse in which the same momentum is transferred in a long time does not cause disconnecting of the structural bonds but the momentum will be transferred to the whole body.

In a more electromagnetic discussion we can find the above mentioned “cause” as in the following: Suppose that the above mentioned first and second waves have the same amplitude. These waves arrive at their electronic aims with the same speed. Consider the magnetic field vectors of the waves. In a constant time interval the change in the magnetic field vector is more in the second one than in the first one; eg in a time interval equal to a quarter of the period of the second one this vector reaches to its maximum from zero in the second one while this is not the case in the first one. Therefore, the speed of the displacement of the magnetic field relative to the electron which is supposed fixed, in the second one is more than in the first one. In simpler words the situation is like that in the second one, one of the two poles of a magnet is moving faster than in the first one. It is obvious that since there is a relative displacement between an electric charge (ie the electron) and a magnetic field (ie one related to the electromagnetic wave, likened to the field of a magnet), there will be a force proportional to the speed of the displacement, exerted on the electric charge, ie the electron (which is normal to the magnetic field vector and to the propagation direction of the wave). It is clear that since this speed of displacement is more in the second one, the force exerted on the electron is also more in the second one.

In this manner the case (b) is also justified: Firstly, since each of the waves has aimed at an electron, the intensity of the totality of the beam or in fact the existence of other waves of the beam aiming at other electrons, cannot have any role in whether a single wave is able to set free an electron or not. Secondly, according to the above discussion, depending on the kind of the metal or in fact on the bond force between the electron and the nucleus of its atom each wave must have a minimum frequency, or in other words must have a minimum slope, or in other words must have a minimum time rate of the field change in order that it can exert the necessary force for releasing the electron.

Some attention to the above electromagnetic discussion shows that if the frequency of the second wave is more than the minimum frequency necessary for releasing electron (ie the threshold frequency), immediately after releasing the electron continuation of the time-change of the magnetic field will cause exertion of the force on the released electron magnitude of which being proportional to the frequency magnitude, ie as the frequency is increased, because of the increase in the speed of the change of the magnetic field the force exerted on the released electron is also increased.

In this manner the case (c) is also justified, because we showed now the proportion of the increase in the frequency to the increase in the force exerted on the released electron being itself proportional to the increase in the kinetic energy of the released electron. But why the slope of the line mentioned in the case (c) is the same for all the metals? Because as we said increase of frequency is proportional to the increase in the kinetic energy of the “released” electron and it is obvious that when an electron is released from the metal then it will be independent of the kind of metal;

in other words photoelectrons released from each metal are the same by nature and don't differ with each other to cause any difference among the curve slopes of different metals.

One can put this question that how the energy transferred from an electromagnetic wave can depend on the wave frequency while in the Poynting vector there is no term involving frequency. In response we should say that as we know the Poynting vector is proportional to the average energy carried by the wave or in other words is proportional to the areas under the curves of the square of the above mentioned first and second waves which is obvious that if their amplitudes are the same, their relevant mentioned areas will be also the same. Then, the energy which an electromagnetic wave can transfer and maybe depend on the frequency is other than the total energy which the wave carries and is independent of frequency (in fact the first is a part of the second).

3 Justification of the Rayleigh scattering and action mechanism of laser

Above manner about the classical justification of the photoelectric effect can be utilized for the classical justification of this fact that the scattering of light will be increased if the frequency of light is increased (which is Lord Rayleigh's investigation): If for simplicity we suppose that a scattering molecule is formed of a heavy positive charge and a light negative charge which without any motion relative to each other are resting beside each other like a dipole, it will be obvious that it will be acceptable that we imagine that in order that the negative charge can go a little away from the positive charge and like a spring oscillate both sides of the positive charge center, it needs a minimum impulse (ie a momentum sufficiently big which is exerted on the lighter negative charge in a time interval sufficiently small). It is obvious that, considering the above discussion about the photoelectric effect, high frequency electromagnetic waves can exert this impulse better than low frequency electromagnetic waves, and so, scattering of high frequency waves done by this dipole is more.

Now let's see how a laser works. Consider a gas laser that the molecules of its gas are excited by an electric discharge in it and radiate. Depending on the kind of the gas and the other conditions, radiation of these molecules covers a definite part of the electromagnetic spectrum. Considering very much smallness of the wavelengths of the electromagnetic waves (of this part of the spectrum) compared with the dimensions of the laser tube, certainly in this part of the spectrum some wavelength or wavelengths will be found that considering the fixed distance between the two mirrors of the laser will be able to amplify itself or themselves after several successive reflections from the mirrors and making successive constructive interferences, while in other wavelengths we shall have destructive interference and consequently unamplifying of the waves. Then the case is simply as the following: Each molecule of the gas in the tube (after being excited) starts to radiate some electromagnetic wave with a definite wavelength (which is the same one to be amplitude) in all the directions and in all the planes of polarization. Those beams of this radiation which are normal to the mirrors will come back on themselves after reflection from the mirrors causing amplification of themselves. Considering the much excessive speed of the electromagnetic waves, we can consider the molecule as a source which is continuously emitting the same wavelength with the same intensity during the amplification of the wave. So the above particular beam will be strongly amplified during the successive going and backing and constructive interference. Of course, different random planes of polarization of this beam are amplified in this manner. Now, if one of the mirrors is such that allows this strongly amplified beam to exit from the tube, we shall have a laser beam consisting of a particular wavelength but with different planes of polarization outside the tube which is related to only an excited molecule. There are, of course, numerous molecules that in this manner will proceed to amplify this particular wavelength, and then our real laser beam outside the tube is a beam consisting of numerous waves like the waves making the beam in our discussion about the photoelectric effect each related to a particular plane of polarization of one of the numerous gas molecules in the tube (as sources producing electromagnetic waves). It is clear that the more the length of the tube, the more the number of the sources producing the waves, ie the excited molecules, will be and then consequently the number of the waves consisting the laser beam outside the tube (which are related to these numerous molecules) will be more, and then the intensity of the laser beam will be more.

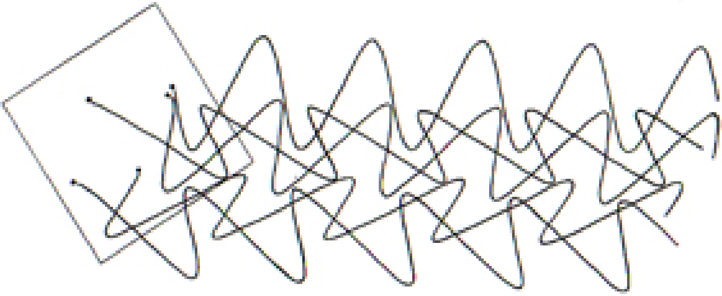

Fig. 1

Fig. 2