IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 14, Issue 2 Ser. I (Mar. – Apr. 2022), PP 34-41
www.iosrjournals.org

Classical Theory of Photoelectric Effect

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Abstract:
Asymmetric electric force exerted due to the asymmetric electric field in the light wave is studied and found to be responsible for photoelectric effect. It suggests that the asymmetric electric force, expressed in terms of field-field interaction, causes to produce an apparent force which is frequency dependent and is always perpendicular to the velocity of the subjected electron and seems to be the actual magnetic force. Therefore, magnetic force in EM waves should be frequency dependent. As frequency increases, the magnetic force exerted by EM wave increases which may be verified experimentally. It further suggests that the electric field and magnetic field in EM waves are not in phase. They should have phase difference of 90 degree.
Keywords: *Photoelectric effect, Electric field, Magnetic field, Asymmetric electric field, Asymmetric magnetic force, Apparent force, Field-field interactions*

Date of Submission: 12-03-2022 Date of Acceptance: 28-03-2022

I. Introduction

It was Wilhem Hallwachs, the student of Hertz, who discovered accidently the photoelectric effect in 1888 by observing that a negatively charged zinc plate discharged rapidly when exposed to ultraviolet light but not for visible light [1]. It was J. J. Thomson, who confirmed in 1897 that the negatively charged electrons or corpuscles were being emitted by the ultraviolet light [2]. A major breakdown in the chain of the investigation was made by Philip Lenard, a former student of Hertz, in 1902 that the number of electrons emitted in this process is affected by the intensity of light illuminating the plate but not their energy. To his surprise, the short wavelength light yielded to produce faster electrons. Based on these observations Lenard and others tried to explain that effect on the basis of classical wave theory of light called "Trigger theories" postulating that the incoming light only triggers the release of electrons [3]. It means the energy of the released electrons is not received from the incident light but it comes from inside the atom whose structure yet to be known. The "Trigger theory" lost its explanatory power when Bohr presented his atomic theory in 1913 [4].

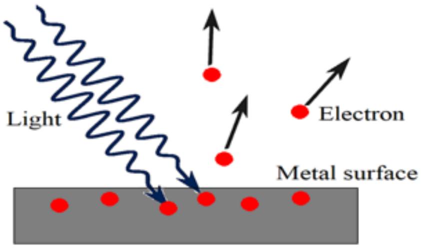

Fig. 1 Representation of Photoelectric Effect.

To the surprise, meanwhile Einstein had published his paper in 1905 providing revolutionary explanation on the photoelectric effect based on his "light quanta" hypothesis proposing that the light behaves as a stream of independent, localized units of energy and could be absorbed by a single electron imparting to it all its energy [5]. He called these localized units of energy as light quanta having energy *hv* where *v* is the frequency of the incident light wave and *h*, a proportionality constant eventually confirmed as plank's constant by experiments yielding the following equation.

$$h\nu = \frac{1}{2}mv^2 + W_0 \quad (1)$$

where $\frac{1}{2}mv^2$ is the maximum kinetic energy of ejected electrons, and W_0 is the work function of the metal. Obviously eq. (1) obeys all the laws of photoelectric effect without any elucidation.

Einstein's hypothesis of "light quanta" was not taken seriously by mathematically adept physicists for just over fifteen years. The reasons are clear. It seemed to be an unnecessary rejection of the highly verified classical theory of radiation. How "light quanta" could possibly explain interference phenomena was always the central objection. There is a big difference between the two natures.

Few things are yet to be answered. What is the type of energy associated with the photon? We don't know really. An electron absorbs energy of a photon means what, do we have clear idea? We don't know about what is happening at that point. If a mass particle is at rest, what are the essentials to displace it from its position? Generally, either a force or a transfer of momentum is required. Is there any role of charge on the electron? We don't know. If there is a charge less particle at the position of electron, can photoelectric effect happen? We don't know really. Light wave, which is an EM wave, is now behaving as a particle too. de Broglie have taken advantage and stated that particle can behave as a wave. Is that wave should be an EM wave? It is not clear.

If we don't have any clear ideas then, why we are blindly following all the things. Einstein never understood that the cause of the discrete energy transfers (photons) which were contradictory to the continuous field theory of matter. In 1954 he wrote to his friend Michael Besso expressing his frustration;

"All these fifty years of conscious brooding have brought me no nearer to the answer to the question, 'What are light quanta?' Nowadays every Tom, Dick and Harry thinks he knows it, he is mistaken."

Einstein himself was not able to accept his hypothesis near about fifty years. It means proposition of the hypothesis was purely based on experimental observations. That lacuna might be disturbing Einstein consequently it might have reflected in the above statement. In this presentation, with the help of the basic knowledge which we have known already, the photoelectric effect is once again analyzed and the outcomes are presented here.

II. Revisiting the Photoelectric Effect with Classical Theory of Electrodynamics

Light consist of waves is already confirmed by interference and diffraction pattern, in particular, Maxwell, who, in 1861 and 1862 published an early form of electromagnetic equations including the Lorentz force law and predicted that the waves in light are also electromagnetic waves propagating with speed c in vacuum with having electric and magnetic field structure as illustrated in Fig. 2(a). To understand the photoelectric effect with this structure, we examine hypothetically such types of one wave incident on a metal surface.

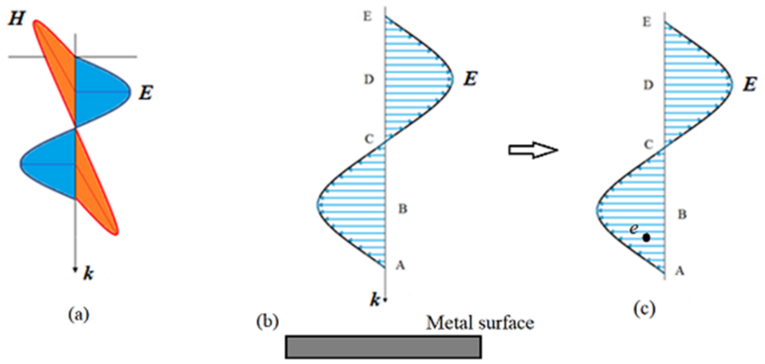

Fig. 2 (a) Representation of electromagnetic fields in an EM wave. (b) Representation of electric field only. (c) Electron subjected to the electric field.

At first we examine the effect of electric field in the wave on the electrons at the metal surface (Fig. 2(b)). As time advances, it progressively interacts with the metal surface and hence with electrons at it. We divide the field into four regions AB, BC, CD and DE. The electric field value at position A is zero producing no force on the subjected electrons. As the wave advances, the field strength subjected to the electron increases. We wish to examine the instant when the subjected electron is at the center of the region AB as illustrated by Fig. 2(c). This electric field exerts an electric force on the electron proportional to the electric field strength at its position in opposite direction of the field. One thing, here, to consider is that the electric field of the wave is not symmetric about the line of force exerted on the electron. Under this situation, the electron cannot be pushed only along the direction of the force eventually the force equation, $\boldsymbol{F} = q\boldsymbol{E}$, may not work properly. To understand the force action more elaborately, we have to take into consideration the electric field of the electron in addition to the applied electric field of the wave and visualize the existence of the electric force in terms of field-field interaction which can be explained as follows.

2.1 Force through field-field interaction

Case (1): In fig. 3(a), the force between the two charges is expressed in terms of their charges. It may be considered as force in terms of charge-charge interaction.

Case (2): In fig 3(b), charge q1 produces electric field $\boldsymbol{E}_1$ around itself. If another charge q2 is brought into the field then the field applies force on the charge. It may be considered as force in terms of field-charge interaction. The force equation is given by $\boldsymbol{F}_2 = q_2 \boldsymbol{E}_1$, where $\boldsymbol{E}_1$ is the electric field produced by charge q_1 at position of charge q_2. Force is mutual. Therefore, charge q_2 also applies force on charge q_1 in terms of field-charge interaction by $\boldsymbol{F}_1 = q_1 \boldsymbol{E}_2$, where $\boldsymbol{E}_2$ is the electric field produced by the charge q_2 at position of charge q_1.

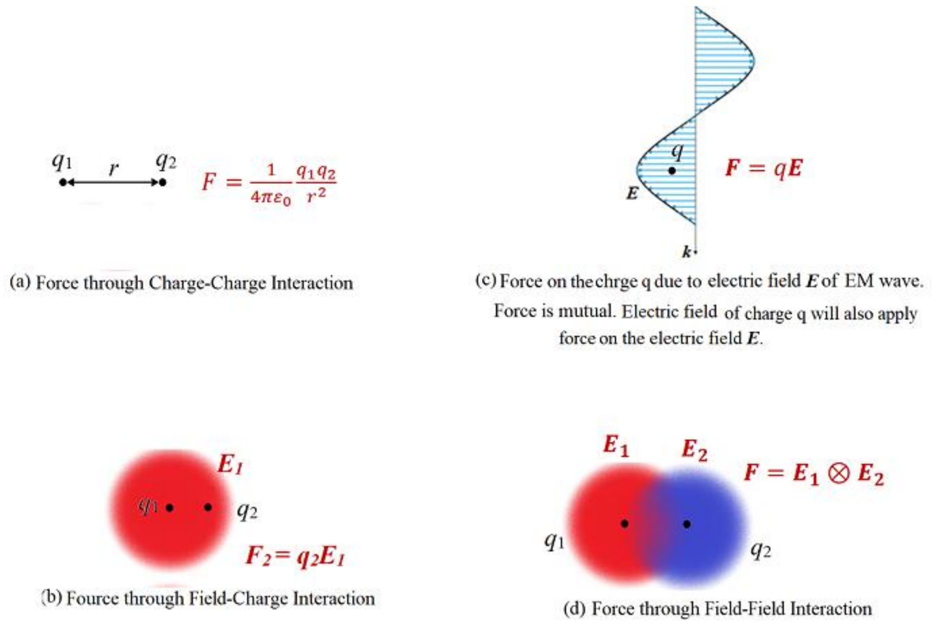

Fig. 3 (a) Force through charge-charge interaction. (b) Force through field-charge interaction. (c) Force is mutual. Charge will apply force on the electric field. (d) Force through field-field interaction.

Case (3): In fig. 3(c), an electric field wave in an electromagnetic wave is propagating with speed of light and interacts with a charge q at an instant. This field also applies force on the charge in terms of field-charge interaction. If $\boldsymbol{E}$ is the electric field of the electric wave at position of the charge q at any instant then the force equation is $\boldsymbol{F} = q\boldsymbol{E}$. But the force is mutual. Hence the charge q should also apply force on the electric field of the wave. As there is no charge associated with electric field of the wave, the electric field of the charge q must apply force on the electric field of the wave which may be considered as force through field-field interactions. Obviously, as the subjected charge q is always associated with its own electric field, therefore, the electric field of the applied wave must apply force on the field of the charge resulting into the force through field-field interactions. Thus finally one can conclude that the electric force exists not in terms of charge-charge interaction or field-charge interaction but it exists in terms of field-field interactions.

Case (4): In fig. 3(d), if two charges are brought close to each other, then force between them, either attractive or repulsive, is existed in terms of their field-field interactions. It means the electric field of first charge exerts force on the electric field of the second charge and vice versa. Thus a new electric force equation is to be developed which could explain the force in terms of the field-field interaction. At present we consider existence of electric force in terms of the field-field interactions for further discussion.

Fig 2(c) is more elaborated in fig. 4 where the effect of electric force through field-field interactions can be understood.

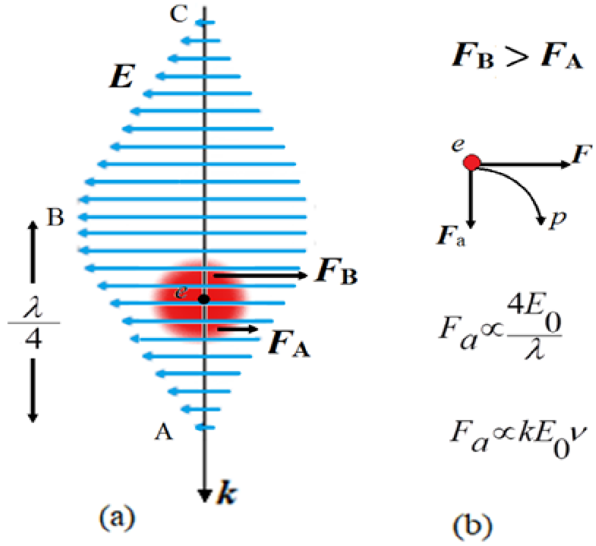

Fig. 4 (a) Asymmetric electric force applied by electric field of the wave on electron's electric field. (b) Electron follows a curved path and pushed into the metal surface.

We are investigating motion of the subjected electron when it is in the region between 'A' and 'B' of the electric field of the wave. Here we divide the electric field of the electron into two hemispheres, upper and lower. Let $\boldsymbol{F}$ be the net electric force divided into two parts $\boldsymbol{F}_A$ and $\boldsymbol{F}_B$ where $\boldsymbol{F}_A$ is the force on the electron's field at its lower hemisphere and $\boldsymbol{F}_B$ is the force on the electron's field at upper hemisphere. Clearly $F_A<F_B$ because of which the net electric force $\boldsymbol{F}$ is asymmetric causing the electron to follow the curved path 'p'. As $F_A<F_B$, the electron gets **pushed into the metal surface** and there no ejection from the metal. As the electron follows a curved path, therefore, it can be imagined as acting under two forces, the net electric force F which is always in opposite direction of the electric field of the wave and other is an apparent force $\boldsymbol{F}_a$ which is proportional to the electric field strength E_0 of the wave and inversely proportional to the distance between points 'A' and 'B'. Further it is always perpendicular to the velocity of the electron and it is in the plane of the electric field of the wave. Actually the apparent force can be true face of magnetic force arising due to the symmetric electric field and asymmetric electric force. Thus,

$$F_a \propto \frac{4E_0}{\lambda} \qquad (2)$$

$$F_a = kE_0\nu \qquad (3)$$

Thus the apparent force F_a is proportional to the frequency of the wave.

While progressing the wave, when the subjected electron at the metal surface comes at position 'B' of the wave, the electric force becomes symmetric and there is no curved path to be followed by the electron.

When the subjected electron comes at the position between point 'B' and 'C' of the wave, once again the electric force becomes asymmetric as shown in fig. 5.

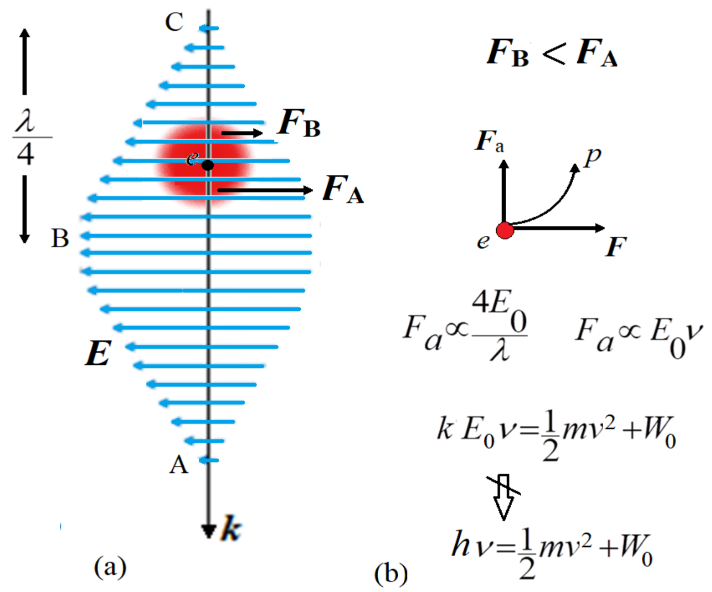

Fig. 5 (a) Asymmetric electric force applied by electric field of the wave on electron's electric field. (b) Electron follows a curved path and pushed away from the metal surface.

Here $F_A > F_B$ because of which the electron follows curved path in upward direction and may be **ejected from the metal surface**. Here again the apparent force, responsible to produce the curved path, is proportional to the frequency of the wave. The work done by this force in pushing the electron at the metal surface in upward direction may be assigned as

$$W = kE_0 \nu \quad (4)$$

Part of this work done will be used to overcome binding energy to release the electron from the metal surface and remaining will be converted into kinetic energy of the electron. If W_0 is the binding energy of the electron then we may have

$$kE_0 \nu = \frac{1}{2} m v^2 + W_0 \quad (5)$$

This equation is similar to the Einstein's equation (3) except kE_0 should be equal to the plank's constant h which seems to be impossible. In Einstein's explanation, one photon is absorbed at one time by an electron. According to this consideration, if one wave is linked to the subjected electron at one time then the amplitude E_0 of the wave should be always constant, since it is emitted by transition of single electron in atom possessing fixed charge and field. Therefore, kE_0 should be always constant for all frequencies of the light waves. More investigation in this regard is needed. Equation (5) relates kinetic energy of the photoelectron with frequency of the incident light wave.

III. Experimental Proof

3.1 Increase of Magnetic Force with increase in Frequency of EM Waves

Asymmetric electric field produces asymmetric electric force which is responsible to produce the apparent force which is always perpendicular to the velocity of the subjected charged particle and it exists only when the charged particle is in motion. Therefore, it creates possibility of the apparent force can be the true face of magnetic force. If it is the fact then it could be experimentally verified. As the apparent force increases with increase in frequency of light wave causing to produce the photoelectric effect and the apparent force if is the true face of magnetic force then, the magnetic force existed by any electromagnetic wave like produced by an antenna should increase with increase in frequency of the wave which could be experimentally verified as explained below.

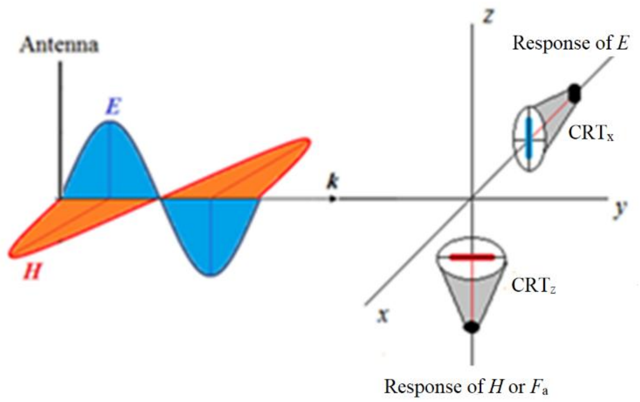

Fig. 6 Experimental arrangement to determine dependence of magnetic force on frequency of EM wave.

Fig. 6 represents the experimental arrangement to detect the dependence of magnetic force on frequency of the EM wave and phase difference between electric and magnetic fields in the wave. The antenna produces EM wave of suitable frequency and amplitude. Two cathode ray tubes (CRTs) can be used to detect response of the electric field and magnetic field in the wave. CRTx is kept perpendicular to the electric field to detect its field strength. CRTz is kept perpendicular to the magnetic field to detect its field strength.

Deflection of CRT*x* will be proportional to the amplitude of the electric field wave. This deflection will not depend on frequency of the wave. According to the classical electrodynamics, there will be no effect of magnetic field wave on deflection of CRT*x* as its electron beam is parallel to the magnetic field. By increasing the frequency of the EM waves with keeping amplitude of the wave constant, we should find there is no change in the deflection of the electron beam of CRTx.

Deflection of CRTz will be proportional to the amplitude of the magnetic field wave. According to the classical electrodynamics, this deflection will not depend on frequency of the wave, since the magnetic force equation is

$$\boldsymbol{F} = q(\boldsymbol{v} \times \boldsymbol{B}) \tag{6}$$

It does not involve the frequency of the wave.

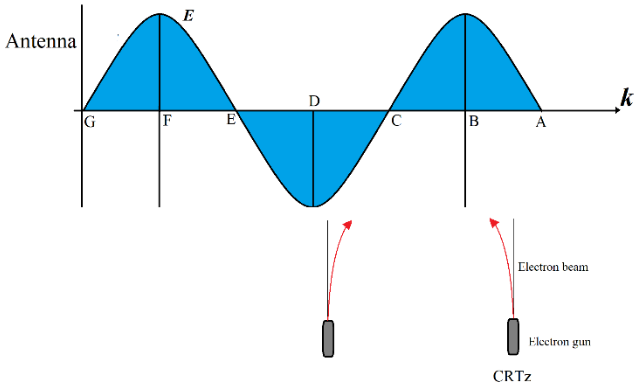

Fig. 7 Deflection of electron beam of CRTz due to asymmetric electric field in EM wave.

Further, there should be no effect of electric field wave on deflection of CRT*z* as its electron beam is parallel to the electric field. By increasing the frequency of the EM waves with keeping amplitude of the wave constant, we should find no change in the deflection of the electron beam of CRTz also. But if the apparent force is actually working as the magnetic force, then with increase in frequency of the wave the deflection of the CRTz should increase though the field strength of the wave is constant. It can be explained by fig. 7.

If the apparent force is the true face of magnetic force then the magnetic field is absent in the wave. From fig. 7, the electric field in the region A to C tries to decelerate the electron beam because of which the electron beam gets deflected into the strong field region. This deflection is proportional to the amplitude E_0 of the wave and inversely proportional to the distance between points A and B which is $\lambda/4$ consequently the deflection is proportional to the frequency of the wave with E_0 is kept constant. The electric field in the region between point C and D tries to accelerate the electron beam because of which the beam gets deflected into the weak field region. Here also the deflection is proportional to the frequency of the wave. This experiment will prove whether the apparent force is working as the true face of magnetic field or not.

This experiment can be performed such as suppose the length of the electron beam of the CRT is 10cm and the accelerating voltage of the final anode is 1000volt then the frequency of the EM wave should be in the range of 1MHz to 100MHz. Produce such an EM wave by an antenna and keep the magnitude of the wave sufficiently strong so as to get deflection of electron beam in CRTs. By keeping the field strength constant and increasing the frequency of the wave from 1MHz to 100MHz in small steps and note the deflections of the CRTs at both positions. With increase in frequency we should found increase in deflection of the CRTz which will confirm the apparent force F_a produced by asymmetric electric field which is working as the magnetic force and responsible to produce the photoelectric effect. On the other hand CRTx should not show any change in the deflection. While doing the experiment we might have to do changes in the frequency range.

3.2 Phase difference between electric and magnetic field waves

If the apparent force is actually working as the magnetic force then there can be a phase difference between electric field wave and magnetic field wave which can be understood using figure 8. When electrons are accelerated, they get pushed into weak field and when they are decelerated then they get pushed into strong electric field.

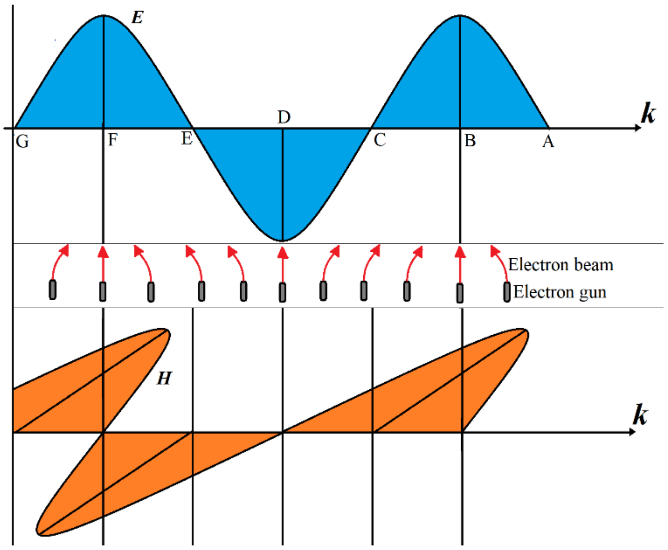

Fig. 8 Representation of magnetic field using deflections of electron beam of CRTz.

The electric field between A to C decelerates the electron because of which they get pushed into the strong field region. The field between C to E accelerates the electron because of which they gets pushed into the weak field region. At positions B, D, F the electric field is symmetric, therefore, there is no deflection of electron beam indicating corresponding magnetic field should be zero. The phase difference can be experimentally verified by using same ramp voltage signal to both CRTs simultaneously. The actual phase difference between electric field and magnetic field in an EM wave should be as like shown in fig. 9 (b).

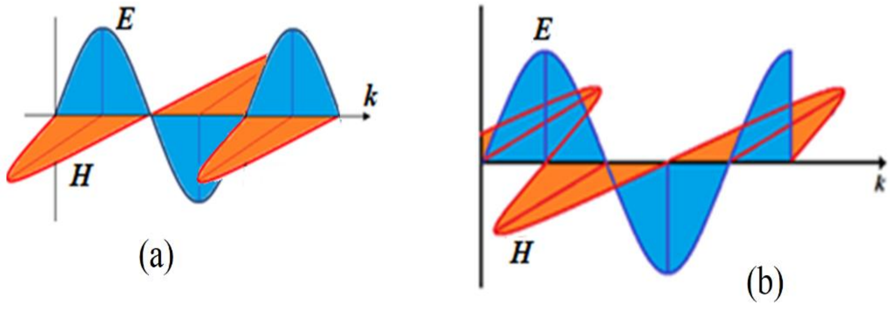

Fig. 9 (a) Represents no phase difference between electric and magnetic field waves in according to the existing classical theory of electrodynamics. (b) Represents the expected phase difference between electric and magnetic field waves from the above discussion.

IV. Discussion

Analysis presented here shows that an asymmetric electric field should produce an asymmetric electric force which could be explained in terms of field-field interaction. Further the asymmetric electric force can be divided into two components, one is the usual Coulomb electric force and the other is an apparent force. The apparent force is always perpendicular to the velocity of the subjected charged particle consequently the particle follows a curved path. Further the apparent force is proportional to the rate at which the electric field changes with distance in perpendicular direction of its polarization. In EM waves, the apparent force is proportional to the frequency of the wave, therefore, it could be responsible to produce the photoelectric effect. Further the properties of the apparent force and that of the magnetic force in EM waves are found to be similar. Thus, if the apparent force is actually working as magnetic force in EM waves then the magnetic force should increase with frequency of EM waves which could be verified by the experimental arrangement suggested in Fig. 9(a). Further study force implies that there should be a phase difference of 90 degree between electric field and magnetic field in EM waves as described in Fig. 9(b). Both things are unexpected according to the usual classical electrodynamics.

V. Conclusion

In EM waves, the magnetic force should increase with increase in frequency which should be responsible to produce the photoelectric effect.

There should be a phase difference of 90 degree between electric field and magnetic field in EM waves as described.

The apparent force produced due to the asymmetric electric force is the true face of the magnetic force, which gives answer to the absentee of magnetic monopoles in the universe.

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