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The Interaction between Photon and Free Electron

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

Based on the quantum mechanics, we discussed the interaction between the photon and free electron. We found: 1.The interaction between the photon and free electron is handedness dependent; 2. Compared to the left handedness photon situation, the frequency of right handedness photon will shift to the more infrared side after its interaction with the free electron and 3.The contribution from the interaction between the magnetic moment of free electron and the magnetic vector of photon to the frequency shift is not handedness dependent.

Keywords: Free electron; photon handedness; solar energy; frequency shift; magnetic moment; photonics.

1. INTRODUCTION

The interaction between the light and the matter has great influence on the evolution of our universe. From the nonliving materials, such as the rock at the roadside to the life materials at low level, such as the plant on the ground to the life materials at high level, such as human being, all change continuously under the light influence.

To understand the interaction between the light and matter is so important that the researchers paid much attention to the light since the beginning of science. Especially, the research in the field has been intensified in the past decade due to the wide application of light in communication, photonics, solar energy utilization, etc [1-2].

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In the research history about the light, it experienced the particle hypothesis [3-4], the wave hypothesis [5-6] and later on the wave-particle duality hypothesis [7]. In some experiments, the light behaviors more like a particle, in some other experiments, the light behaviors more like a wave. Then, in scientific fields, a new name, "photon", is invented to represent the light. The problem is: if we take the photon as a particle, we have to know how many times of vibration of light should be cut off and take this part of light as a photon, otherwise, the situation will become the light (photon) can vibrate arbitrary times at will. The same situation for the wave hypothesis of photon, we can't say the photon can vibrate as many times as it like before the photon is absorbed by the matter. The wave must be cut off at certain time length or periods. Even we already define the duality of wave-particle of light, the problem is still there, not solved. This means to us that even though the long time research on light, some fundamental aspects are still not so clearly understood. Therefore, two years ago we turn our attention onto these fundamental topics on the light.

From the previous work [8], we demonstrate that the light is not continuous as we think before, but discontinuous instead, that is, each part of the light we can call it "energy corpuscle" following the definition of Issac Newton or "photon" by the definition of scientific world later on. The part of light as a photon only has one complete period of vibration. In that paper, we directly answer the question in above paragraph, that is, how many times the photon can vibrate when it interacts with the matter.

Now we hope to go further to explain the detail of the interaction between the photon and the matter. We would like to start the topic from the simplest system, that is, the interaction between photon and a free electron. In fact, this topic has been studied before and the related phenomenon is called Compton Scattering [9-10]. The Compton Scattering correctly describe the frequency shift during the light scattering but his explanation is based on the free electron approximation, that is, the system is not really the interaction between the light and free electron. In this paper, we will more focus on the behavior of free electron under the interaction with photon.

2. THEORY

2.1 The Interaction between Photon and a Free Electron

From Fig. 1, we know that the photon will create the potential energy at the origin. As we know, the photon has two different handedness, therefore, the right handedness photon will create the potential energy at origin (VI), which is different from the potential energy created by the left handedness photon (VII).

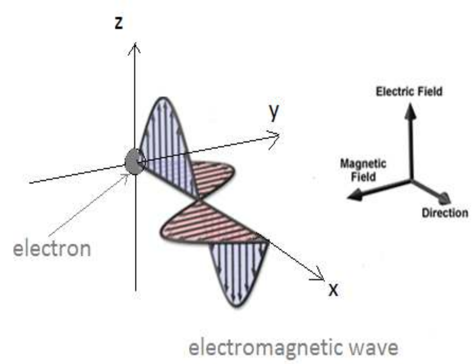

Fig. 1. The light propagates along x axe and an electron locates at the origin of Cartesian coordinate

$$\text{VI}=\int F dt = -\frac{\sqrt{2}}{2} ec \times B_{y0} cos(t)\hat{z} - \frac{\sqrt{2}}{2} eE_{z0} cos(t)\hat{z} - \frac{\sqrt{2}}{2} ec \times B_{y0} cos(t)\hat{x} - \frac{\sqrt{2}}{2} eE_{z0} cos(t)\hat{x} \quad (1)$$

$$\text{VII}=\frac{\sqrt{2}}{2} ec \times B_{y0} cos(t)\hat{z} - \frac{\sqrt{2}}{2} eE_{z0} cos(t)\hat{z} + \frac{\sqrt{2}}{2} ec \times B_{y0} cos(t)\hat{x} - \frac{\sqrt{2}}{2} eE_{z0} cos(t)\hat{x} \quad (2)$$

Where B_{y0} is the magnitude of the magnetic vector of the photon; E_{z0} is the magnitude of the electric vector of the photon.

Based on the quantum mechanics, a free electron can be described by

$$-\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}\right)\Psi(x,y,z,t) = i\hbar\frac{\partial\Psi(x,y,z,t)}{\partial t} \quad (3)$$

Now the free electron met the photon at the origin of coordinate, the photon will apply the force on the free electron through the interaction between the free electron and the magnetic component and electric component of the photon, just like the electron moving on the energy potential created by the right handedness photon (VI) or the left handedness photon (VII).

For the situation of the right handedness of photon, the eq. (3) becomes,

$$\left(-\frac{\hbar^2}{2m}\left(\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}\right)-\frac{\sqrt{2}}{2}ec\times B_{y0}cos(t)\hat{z}-\frac{\sqrt{2}}{2}eE_{z0}cos(t)\hat{z}-\frac{\sqrt{2}}{2}ec\times B_{y0}cos(t)\hat{x}-\frac{\sqrt{2}}{2}eE_{z0}cos(t)\hat{x}\right)\Psi(x,y,z,t)=i\hbar\frac{\partial\Psi(x,y,z,t)}{\partial t} \quad (4)$$

In z direction,

$$\left(-\frac{\hbar^2}{2m}\frac{\partial^2}{\partial z^2}-\frac{\sqrt{2}}{2}ec\times B_{y0}cos(t)-\frac{\sqrt{2}}{2}eE_{z0}cos(t)\right)\Psi(z,t)=i\hbar\frac{\partial\Psi(z,t)}{\partial t} \quad (5)$$

Suppose $\Psi(z,t)=\Psi(z)\Psi(t)$, then

$$-\frac{1}{\Psi(z)}\frac{\hbar^2}{2m}\frac{\partial^2\Psi(z)}{\partial z^2}=\frac{1}{\Psi(t)}\left(i\hbar\frac{\partial}{\partial t}+\frac{\sqrt{2}}{2}ec\times B_{y0}cos(t)+\frac{\sqrt{2}}{2}eE_{z0}cos(t)\right)\Psi(t) \quad (6)$$

Suppose $-\frac{1}{\Psi(z)}\frac{\hbar^2}{2m}\frac{\partial^2\Psi(z)}{\partial z^2}=\mathrm{K}_0$ and $\mathrm{K}_1=\frac{\sqrt{2}}{2}ec\times B_{y0}+\frac{\sqrt{2}}{2}eE_{z0}$

We obtain,

$$-\frac{\hbar^2}{2m}\frac{\partial^2\Psi(z)}{\partial z^2}=\mathrm{K}_0\Psi(\mathrm{z}) \quad \text{and} \quad \mathrm{i}\hbar\frac{\partial\Psi(\mathrm{t})}{\partial\mathrm{t}}+\mathrm{K}_1\cos(\mathrm{t})\Psi(\mathrm{t})=\mathrm{K}_0\Psi(\mathrm{t}) \quad (7)$$

From $\mathrm{i}\hbar\frac{\partial\Psi(\mathrm{t})}{\partial\mathrm{t}}+\mathrm{K}_1\cos(\mathrm{t})\Psi(\mathrm{t})-\mathrm{K}_0\Psi(\mathrm{t})=0$ (8)

$$\frac{\partial\Psi(\mathrm{t})}{\partial\mathrm{t}}+\frac{\mathrm{K}_1}{\mathrm{i}\hbar}\cos(\mathrm{t})\Psi(\mathrm{t})-\frac{\mathrm{K}_0}{\mathrm{i}\hbar}\Psi(\mathrm{t})=0 \quad (9)$$

We obtain,

$$\Psi(\mathrm{t})=\mathrm{A}(\cos\left(-\frac{\mathrm{K}_1}{\hbar}\cos(\mathrm{t})+\frac{\mathrm{K}_0}{\hbar}\mathrm{t}\right)-\mathrm{i}\sin\left(-\frac{\mathrm{K}_1}{\hbar}\sin(\mathrm{t})+\frac{\mathrm{K}_0}{\hbar}\mathrm{t}\right)) \quad (10)$$

From $-\frac{1}{\Psi(\mathrm{z})}\frac{\hbar^2}{2\mathrm{m}}\frac{\partial^2\Psi(\mathrm{z})}{\partial\mathrm{z}^2}=\mathrm{K}_0$, then,

$$-\frac{\hbar^2}{2\mathrm{m}}\frac{\partial^2\Psi(\mathrm{z})}{\partial\mathrm{z}^2}=\mathrm{K}_0\Psi(\mathrm{z}) \quad (11)$$

$$\frac{\partial^2\Psi(\mathrm{z})}{\partial\mathrm{z}^2}+\frac{2\mathrm{mK}_0}{\hbar^2}\Psi(\mathrm{z})=0 \quad (12)$$

We got,

$$\Psi(\mathrm{z})=\mathrm{A}'(\cos\left(\frac{\sqrt{2\mathrm{mK}_0}}{\hbar}\right)\mathrm{z}+\mathrm{i}\sin\left(\frac{\sqrt{2\mathrm{mK}_0}}{\hbar}\right)\mathrm{z}) \quad (13)$$

Similarly, in x direction, we can get,

$$\Psi(\mathrm{t}) = \mathrm{A}''(\cos\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right) - \mathrm{i}\sin\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right)) \quad (14)$$

$$\Psi(\mathrm{x}) = \mathrm{A}'''(\cos\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x} + \mathrm{i}\sin\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x}) \quad (15)$$

For y direction, we can get,

$$-\frac{\hbar^2}{2\mathrm{m}}\frac{\partial^2\Psi(\mathrm{y})}{\partial \mathrm{y}^2} = \frac{1}{3}\mathrm{E}_0^0\Psi(\mathrm{y}) \quad (16)$$

$$\frac{\partial^2\Psi(\mathrm{y})}{\partial \mathrm{y}^2} + \frac{2\mathrm{mE}_0^0}{3\hbar^2}\Psi(\mathrm{y}) = 0 \quad (17)$$

$$\Psi(\mathrm{y}) = \mathrm{A}'''(\cos\left(\frac{\sqrt{2/3\mathrm{mE}_0^0}}{\hbar}\right)\mathrm{y} + \mathrm{i}\sin\left(\frac{\sqrt{2/3\mathrm{mE}_0^0}}{\hbar}\right)\mathrm{y}) \quad (18)$$

where E_0^0 is the total energy of free electron without interaction with photon.

By the interaction between the photon and electron, the electron got the kinetic energy.

In Z direction,

$$E_{kz} = \frac{1}{m}\int_0^{\frac{\lambda}{c}}\int_0^{\frac{\lambda}{c}} K_1^2\, sin^2 t dt^2$$

$$= \frac{1}{m}\int_0^{\frac{\lambda}{c}}\int_0^{\frac{\lambda}{c}} K_1^2\, (\frac{1}{2} + \frac{1}{2}cos2t)dt^2$$

$$= \frac{K_1^2}{2m}(\frac{1}{2}t^2 - \frac{1}{4}cos2t)_0^{\frac{\lambda}{c}}$$

$$= \frac{K_1^2}{4m}(\frac{\lambda^2}{c^2} - \frac{1}{2}cos\frac{2\lambda}{c} + \frac{1}{2}) \quad (19)$$

Similarly, in x direction,

$$E_{kx} = \frac{K_1^2}{4m}(\frac{\lambda^2}{c^2} - \frac{1}{2}cos\frac{2\lambda}{c} + \frac{1}{2}) \quad (20)$$

So, the total energy for electron obtained is,

$$E_{kt} = E_{kz} + E_{kx} \quad (21)$$

After the interaction, the photon lost the same amount of energy, therefore,

$$\hbar\nu = \hbar\nu_0 - E_{kt} \quad (22)$$

The frequency of the photon will reduce $\Delta v = v_0 - v = \frac{E_{kt}}{\hbar}$.

In fact, we may be more interested in the electron behavior in the process of the interaction between the photon and electron.

From the equations above, we know that

$$K_0 = \frac{1}{3}E_0^0 + E_{kz} = \frac{1}{3}E_0^0 + E_{kx}$$

Since $E_{kx} = E_{kz}$, therefore, the wave function of the electron becomes,

$$\Psi(\mathrm{x,y,z,t}) = \mathrm{A}(\cos\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x} + \mathrm{i}\sin\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x})$$

$$(\cos\left(\frac{\sqrt{2/3\mathrm{mE_0^0}}}{\hbar}\right)\mathrm{y} + \mathrm{i}\sin\left(\frac{\sqrt{2/3\mathrm{mE_0^0}}}{\hbar}\right)\mathrm{y})$$

$$(\cos\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{z} + \mathrm{i}\sin\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{z})$$

$$(\cos\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right) - \mathrm{i}\sin\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right)) \quad (23)$$

The probability distribution of the electron is,

$$\Psi^2(\mathrm{x,y,z,t}) = \mathrm{A'}(\cos^2\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x} - \sin^2\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x})$$

$$(\cos^2\left(\frac{\sqrt{2/3\mathrm{mE_0^0}}}{\hbar}\right)\mathrm{y} - \sin^2\left(\frac{\sqrt{2/3\mathrm{mE_0^0}}}{\hbar}\right)\mathrm{y})$$

$$(\cos^2\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{z} - \sin^2\left(\frac{\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{z})$$

$$(\cos^2\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right) - \sin^2\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right)) \quad (24)$$

Where A and A$'$ are the normalization factors;

$$\mathrm{K_0} = 1/3E_0^0 + \mathrm{E_{kz}} = 1/3E_0^0 + \mathrm{E_{kx}},\ \mathrm{K_1} = \frac{\sqrt{2}}{2}ec \times B_{y0} + \frac{\sqrt{2}}{2}eE_{z0}$$

The equation (24) can be further simplified as,

$$\Psi^2(\mathrm{x,y,z,t}) = \mathrm{A}\left(\cos\left(\frac{2\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{x}\right)\left(\cos\left(\frac{2\sqrt{2/3\mathrm{mE_0^0}}}{\hbar}\right)\mathrm{y}\right)\left(\cos\left(\frac{2\sqrt{2\mathrm{mK_0}}}{\hbar}\right)\mathrm{z}\right)(\cos 2\left(-\frac{\mathrm{K_1}}{\hbar}\sin(\mathrm{t}) + \frac{\mathrm{K_0}}{\hbar}\mathrm{t}\right))$$

$(x \le \lambda,\ y \le \lambda,\ z \le \lambda,\ t \le T)$ (25)

Till now, it becomes obvious that, due to the interaction between the photon and electron, the distribution of the probability to find the electron in the space is not homogeneous, but x, y, z and t dependent instead. Compared to the undisturbed free electron, the electron will be more frequently up and down or go front and back at z and x direction, but keep the same probability distribution in y direction as undisturbed free electron. This can be explained by the fact that

$$\frac{2\sqrt{2\mathrm{mK_0}}}{\hbar} > \frac{2\sqrt{2/3\mathrm{mE_0^0}}}{\hbar}$$

Since the light has two different handedness, the discussion above is the right handedness situation. Now we consider the left handedness of light situation, the energy potential created by the left handedness photon at electron location is described by VII (eq.3). Then following the same procedure as above, we can obtain,

$$\Psi^2(\mathrm{x,y,z,t}) = \mathrm{A}\left(\cos\left(\frac{2\sqrt{2\mathrm{mK}_0}}{\hbar}\right)\mathrm{x}\right)\left(\cos\left(\frac{2\sqrt{2/3\mathrm{mE}_0^0}}{\hbar}\right)\mathrm{y}\right)\left(\cos\left(\frac{2\sqrt{2\mathrm{mK}_0}}{\hbar}\right)\mathrm{z}\right)\left(\cos 2\left(-\frac{\mathrm{K}_1}{\hbar}\mathrm{SIN(t)}+\frac{\mathrm{K}_0}{\hbar}\mathrm{t}\right)\right)$$

$(x \le \lambda,\ y \le \lambda,\ z \le \lambda,\ t \le T)$ (26)

Where A is the normalization factor,

$K_0 = 1/3E_0^0 + E_{kz} = 1/3E_0^0 + E_{kx}$, $E_{kx} = E_{kz} = \frac{K_1^2}{4m}\left(\frac{\lambda^2}{c^2} - \frac{1}{2}\cos\frac{2\lambda}{c} + \frac{1}{2}\right)$

$K_1 = -\frac{\sqrt{2}}{2}ec \times B_{y0} + \frac{\sqrt{2}}{2}eE_{z0}$

It is noted that even though the expressions of $\Psi^2(x,y,z,t)$ are the same (see eq.(25) and eq.(26)) for the right and left handedness photon situations, but due to K_1 is different, then E_{kx} , E_{kz} and K_0 are also different in the right and left handedness situations. That means the energy obtained by electron during the interaction between the photon and electron is different from the left to right handedness photons. The consequence is the frequency reduction of photon is also different for the left and right handedness photon situations. Since K_1 is smaller than that in the right handedness photon situation, therefore, the frequency reduction will be less than that of right handedness photon situation. For the electron, the energy obtained by electron is less compared to that in the right handedness photon situation. That means the electron will be less disturbed by the interaction with the left handedness photon.

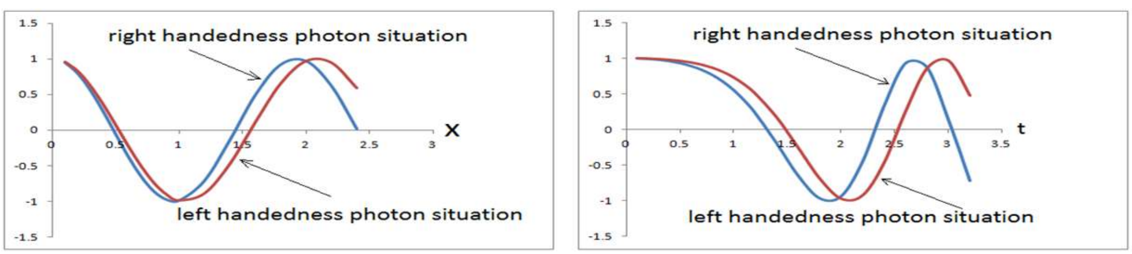

Fig. 2. Ψ^2(x)~x (above left) and Ψ^2(t)~t (above right)

Supposing: B_{y0}=1, E_{z0}=0, m=0, E^0_0=1, E_{kz}=1, $\hbar$=1, K_0=1/3+1 for right handedness photon, K_0=1/3+0.8 and Ekz=0.9 for left handedness photon.

This result does surprise us because it contradicts with our conventional understanding about the interaction between the photon and free electron. Intuitively, we think the interaction between both handedness photons and free electron should be the same because a free electron has no handedness at all. This distinguished behavior of electron for the left and right handedness photon situations may come from the electric/magnetic asymmetry embedded in the Maxwell equation. The electric/magnetic asymmetry may be one of the reasons why our universe is over occupied by the left handedness, especially for the process involving photon. Our result also implies that our universe evolves in different speed for the left and right handedness, therefore, the handedness symmetry was broken. We can conjecture that this handedness symmetry broken is involved in other symmetry broken of our universe, such as matter and antimatter symmetry broken [11]. This subject should be very interesting for our future effort.

2.2 The Induced Magnetic Dipole Moment

From the discussion above, we know that the photon interacts with free electron in a different way for the left and right handedness. This effect mainly comes from the handedness of photon because a free electron doesn't show any different handedness. Here we would like to discuss the effect of the interaction between the different handedness photon with electron spin.

From the electromagnetic theory, we already know the photon carries angular moment. When a photon is absorbed by the object, the total angular moment of the object will become the original angular moment plus the angular moment of photon absorbed by the object. However, for a free electron, the angular moment of photon can't directly transfer to free electron because a free electron can't absorb the photon. But a free electron does have its magnetic moment due to the spin. This magnetic moment of electron will interact with the photon magnetic vector. As we discussed in above paragraph, the magnetic vector of photon has different orientation for different handedness photon. As we all know if electron passed the asymmetric magnetic fields, the electron will turn to different direction due to the different orientation of magnetic moment of electron relative to the magnetic fields (Zeeman effect).

The total spin magnetic moment of electron equals the intrinsic one plus "induced one" by photon. It should be noticed that the "induced" magnetic moment is perpendicular to the intrinsic one in direction as we illustrate in Fig. 3.

Following the quantum mechanics, the Schrodinger equation should be,

$$(-\frac{\hbar^2}{2I}\frac{\partial^2}{\partial\varphi^2} \pm \mu_e B)\Psi(\varphi,t) = i\hbar\frac{\partial\Psi(\varphi,t)}{\partial t} \quad (27)$$

$$(-\frac{\hbar^2}{2I}\frac{\partial^2}{\partial\varphi^2} \pm \mu_e B_{y0} cos(\varphi) cos(2\pi\omega_0 t))\Psi(\varphi,t) = i\hbar\frac{\partial\Psi(\varphi,t)}{\partial t} \quad (28)$$

Where I is the inertia momentum of free electron; μ_e is the electron magnetic moment; B is the magnetic vector of the photon; B_{y0} is the magnitude of the magnetic vector of photon in y direction.

Suppose $\varphi=\varphi_0+2\pi\omega t$, where ω is the frequency of electron spin. For simplification, set $\varphi_0=0$, then,

$$(-\frac{\hbar^2}{2I}\frac{\partial^2}{\partial\varphi^2} \pm \mu_e B_{y0} cos(2\pi\omega t) cos(2\pi\omega_0 t))\Psi(\varphi,t) = i\hbar\frac{\partial\Psi(\varphi,t)}{\partial t} \quad (29)$$

$$-\frac{\hbar^2}{2I}(\frac{\partial^2}{\partial\varphi^2})\Psi(\varphi)\Psi(t) = (\boldsymbol{i}\hbar\frac{\partial}{\partial t} \mp \mu_e B_{y0} cos(2\pi\omega t) cos(2\pi\omega_0 t))\Psi(\varphi)\Psi(t) \quad (30)$$

$$-\frac{1}{\Psi(\varphi)}\frac{\hbar^2}{2I}(\frac{\partial^2}{\partial\varphi^2})\Psi(\varphi) = \frac{1}{\Psi(t)}(i\hbar\frac{\partial}{\partial t} \mp \mu_e B_{y0} cos(2\pi\omega t) cos(2\pi\omega_0 t))\Psi(t) \quad (31)$$

$$-\frac{1}{\Psi(\varphi)}\frac{\hbar^2}{2I}\frac{\partial^2\Psi(\varphi)}{\partial\varphi^2}\Psi(\varphi) = \boldsymbol{E_s} = \frac{\mathbf{1}}{\Psi(t)}(i\hbar\frac{\partial}{\partial t} \mp \mu_e B_{y0} cos(2\pi\omega t) cos(2\pi\omega_0 t))\Psi(t) \quad (32)$$

Where $\mathbf{E_s}$ is the Eigenvalue of the electron spin.

From the left side of eq. (33), we obtain,

$$-\frac{\hbar^2}{2I}\frac{\partial^2\Psi(\varphi)}{\partial\varphi^2} = E_s\Psi(\varphi) \quad (33)$$

then, we have, $\Psi(\varphi) = A'\exp(\pm i\frac{\sqrt{2IE_s}}{\hbar}\varphi)$ (34)

From the right side of eq.(32), we obtain,

$$(i\hbar\frac{\partial}{\partial t} \mp \mu_e B_{y0}\cos(2\pi\omega t)\cos(2\pi\omega_0 t))\Psi(t) = E_s\Psi(t) \quad (35)$$

$$\frac{\partial\Psi(t)}{\partial t} \mp \frac{\mu_e B_{y0}}{i\hbar}\cos(2\pi\omega t)\cos(2\pi\omega_0 t)\Psi(t) = \frac{E_s}{i\hbar}\Psi(t) \quad (36)$$

$$\frac{\partial\Psi(t)}{\partial t} + (-\frac{E_s}{i\hbar} \mp \frac{\mu_e B_{y0}}{i\hbar}\cos(2\pi\omega t)\cos(2\pi\omega_0 t))\Psi(t) = 0 \quad (37)$$

Then we obtain,

$$\Psi(t) = Aexp(\frac{E_s}{i\hbar}t \pm \frac{\mu_e B_{y0}}{i\hbar}\frac{1}{1-\frac{\omega^2}{\omega_0^2}}(\frac{cos(2\pi\omega t)sin(2\pi\omega_0 t)}{2\pi\omega_0} - \frac{\omega}{2\pi\omega_0^2}sin(2\pi\omega t)cos(2\pi\omega_0 t))) \quad (38)$$

The complete wave function to describe the effect of photon on the spin momentum of electron is $\Psi(\varphi, t) = \Psi(\varphi)\Psi(t)$.

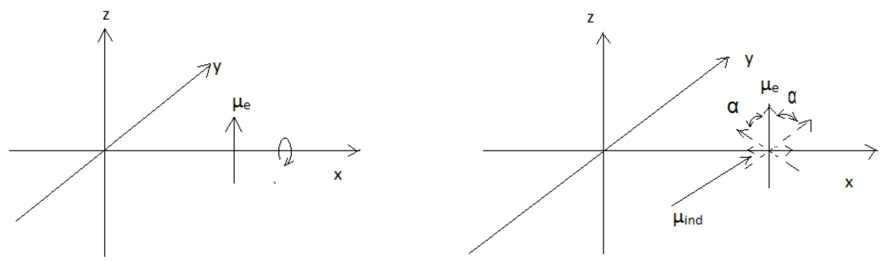

Fig. 3. The illustration of the interaction between the magnetic moment of electron and the photon

The complete turn situation of magnetic moment of electron (above left) and incomplete tune situation of magnetic moment of electron (above right)

From the eq. (38), it is clear that the interaction between the photon magnetic vector and the magnetic moment of electron is t, ω, ω_0 and B_{y0} dependent. The most important is that when the intrinsic spin frequency of electron equals the frequency of the photon, the second term in eq.(38) will make the system in resonance. In the resonance, the interaction between the electron and different handedness photons will become the largest and easier to be observed experimentally.

This kind of interaction between the different handedness photons and electron makes the electron get extra spin in the direction perpendicular to the intrinsic spin of electron (see Fig. 3). This interaction between the handedness photon and electron has two situations. First the interaction between the photon and electron makes the electron magnetic vector complete turn, the induced magnetic moment will keep the same direction which is perpendicular to the intrinsic electron magnetic moment vector. Second is that the interaction between the photon and electron can`t make the intrinsic electron moment vector finish complete turn but just back and forth turn around equilibration position, then, the induced moment will show front and back oscillation (see Fig. 3).

From the discussion in 2.1, we know that the interaction between the photon and electron is handedness dependent. This handedness dependence of the interaction between the photon and free electron can be applied to improve the solar energy conversion but the influence of photon on the magnetic moment of free electron is not handedness dependent. Our result here demonstrates that compared to the left handedness photon, the right handedness photon will become easier to be converted to the electric energy in the solar energy conversion process. This property in the interaction between the photon and free electron can find wide application in the utilization of the solar energy.

In paragraph 2.1, we know the photon will reduce the frequency due to the interaction between the photon and electron. Here we would add the extra term into the eq. (22). This extra term comes from the fact that the electron gets extra rotation energy. The extra rotation energy for electron obtained from photon is, For the complete turn situation,

$$E_{rot} = 2\mu_e B_{y0} \frac{1}{1-\frac{\omega^2}{\omega_0^2}} \left(\frac{cos(2\pi\omega t) sin(2\pi\omega_0 t)}{2\pi\omega_0} - \frac{\omega}{2\pi\omega_0^2} sin(2\pi\omega t) cos(2\pi\omega_0 t)\right)_0^{\lambda/c}$$

$$=2\mu_e B_{y0} \frac{1}{1-\frac{\omega^2}{\omega_0^2}} \left(\frac{\omega sin(\frac{2\pi\omega\lambda}{c}) cos(2\pi n)}{2\pi\omega_0^2}\right) \quad \text{(where n is integer)} \tag{39}$$

For the incomplete turn situation,

$$E_{rot} = 2\mu_e B_{y0} \frac{1}{1-\frac{\omega^2}{\omega_0^2}} \left(\frac{\omega sin(\frac{2\pi\omega\lambda}{c}) cos(2\pi n)}{2\pi\omega_0^2}\right) \frac{\alpha}{\pi} \tag{40}$$

Then, the total frequency shift of photon after interaction with a free electron will be

$$\hbar v = \hbar v_0 - E_{kt} - 2\mu_e B_{y0} \frac{1}{1-\frac{\omega^2}{\omega_0^2}} \left(\frac{\omega sin\left(\frac{2\pi\omega\lambda}{c}\right) cos(2\pi n)}{2\pi\omega_0^2}\right) \quad \text{for complete turn situation and}$$

$$\hbar v = \hbar v_0 - E_{kt} - 2\mu_e B_{y0} \frac{1}{1-\frac{\omega^2}{\omega_0^2}} \left(\frac{\omega sin(\frac{2\pi\omega\lambda}{c}) cos(2\pi n)}{2\pi\omega_0^2}\right) \frac{\boldsymbol{\alpha}}{\boldsymbol{\pi}} \quad \text{for incomplete turn situation.}$$

3. CONCLUSION

From the discussion above, we found that the interaction between the photon and free electron is handedness dependent. But the interaction between magnetic moment of free electron and the magnetic vector of photon is not handedness dependent. Compared to the left handedness photon situation, the frequency of the right handedness photon will shift to the more infrared side after its interaction with electron. This handedness dependence for the interaction between the photon and electron comes from the asymmetry of the magnetic and electric vectors embedded in Maxwell equation. The result of this work can find wide application in photonics, communication and solar energy utilization. For example, we can use the right handedness photon to improve the solar energy conversion efficiency.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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