Estimating Lamb Shift by Using Virtual Photons

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Abstract:

The virtual photon can be used to calculate the ground state energy levels of hydrogen atom and helium atom. The calculation method is relatively simple and easy to understand. The Lamb shift is a problem in quantum electrodynamics. To explain the causes of Lamb's shift, more complex calculations and various assumptions are needed. It is tested that there is a clear difference between the $2S^{1/2}$ orbital of the hydrogen atom and the $2P^{1/2}$ orbital, which involves the virtual photon exchange between the electron and the proton, which inevitably causes the difference of the virtual photon exchange mode. The difference in the way of this virtual photon exchange may cause the energy loss of the electron proton interactions of the $2S^{1/2}$ orbital and $2P^{1/2}$ orbital to differ. Through the calculations in this paper, it is found that if the $2S^{1/2}$ orbital virtual photon exchange requires additional transmission of a longer distance, the efficiency of virtual photon energy exchange will be slightly reduced. Thus the energy lost by the $2S^{1/2}$ orbital is less than the energy lost by the $2P^{1/2}$ orbital. This difference in energy reflects Lamb's shift. The calculation results are consistent with the experimental results on the order of magnitude. This suggests that Lamb shift may also be caused by changes in the efficiency of virtual photon exchange between particles.

Key words: Virtual photon; Lamb movement; Fine structure constant

1 Introduction

In 2012, I proposed Maxwell's equations based on virtual space-time[1,2], and improved the existing Maxwell equations. Then I used a solution from the new Maxwell's equations to find out the solution of the virtual photon [2,3].

Different from the electromagnetic wave solution corresponding to the photon, the solution of the virtual photon spans two time and space [2,3]. Some part of them are located in the virtual space and time. So if two particles interact, it will lead to the exchange of virtual photons. The probability that such a virtual photon can be exchanged is closely related to the energy of the particle in virtual space time.

According to the idea that particle interaction is essentially virtual photon exchange, I accurately

solved the ground state energy of helium atom [2,4]. The results of the solution are very close to the experimental results. This confirms to some extent the rationality of the existence of virtual photons.

After several years of thinking, I found that the existence of virtual photons also helps to explain the Lamb shift in a more concise way - where quantum mechanics cannot be explained, and quantum electrodynamics requires very complicated assumptions to explain

2 The probability of virtual photon exchange

2.1 The exchange probability of virtual photon carried by electromagnetic field

When calculating the ground state energy level of a helium atom, I assume that for electromagnetic interactions, the probability of a particle emitting or absorbing a virtual photon is α. However, I have not given a reason in this article. As I gradually understand the nature of the virtual photon, here I try to explain the origin of the virtual photon exchange probability α.

Virtual photons are also electromagnetic waves in nature, so the transmission of virtual photons is closely related to the nature of electromagnetic fields. Unlike the electromagnetic waves corresponding to ordinary photons, the virtual photon wave function solved by the virtual photon wave equations also contains the spatial position of the virtual space-time [3]. Therefore, the discussion of the exchange of virtual photons must also involve some important properties of virtual space time.

From the perspective of Maxwell's equations based on virtual space time, the generalized magnetic charge and the generalized charge are not equal. According to the calculation results of paper [1,2], the generalized magnetic charge is larger than the generalized charge, and the generalized magnetic charge is about 137 times of the generalized charge. This also means that for a particle, the electromagnetic field energy in real space time accounts for about 1/137 of the total energy of the electromagnetic field in virtual space time. Therefore, it can be seen that electromagnetic interaction occurs in real space time, involving only 1/137 of the total energy. . This also means that the probability that the real space time electric field emit energy is about 1/137, which is the fine structure constant α.

$$j_{emittion} = \alpha \qquad (1)$$

The same is true for the absorption of virtual photons:

$$j_{absorption} = \alpha \qquad (2)$$

Although this is not a strict derivation process, material changes have their own laws. Therefore, if a conclusion can be confirmed by experiments, it means that our current theoretical analysis still has limitations. Some examples will be given later to analyze this conclusion. Due to the symmetry requirements of electromagnetic interactions, the probability of emitting virtual photon and absorbing virtual photon is generally the same, so that:

$$j = j_{emittion} = j_{absorption} = \alpha \qquad (3)$$

2.2 The virtual photon energy exchange efficiency between two different mass particles interaction

If the two interacting particles are of different mass, it will affect the energy exchange efficiency of the virtual photons. After all, between the two equal mass particles interacts and two different mass particles interacts, the calculation results are very different in classical mechanics.

Here we first analyze the interaction between electron and proton from the perspective of classical mechanics. Assume that the electron mass is m_e, the proton mass is m_p, the initial velocity of the electron is v, the initial kinetic energy of the electron is $E_0 = \frac{1}{2} m_e v^2$, the velocity after the collision is v_e, and the kinetic energy after the electron collision is $E_e = \frac{1}{2} m_e {v_e}^2$; the initial velocity of the proton is 0, and the velocity after the collision is v_p. After the proton collision, the kinetic energy is $E_p = \frac{1}{2} m_p {v_p}^2$. Then according to momentum conservation and energy conservation laws, we have the following relationship (for simplicity, the black body represents the vector and the italic letters represent the corresponding scalar):

$$\begin{cases} m_e \mathbf{v} = m_e \mathbf{v}_e + m_p \mathbf{v}_p \\ \frac{1}{2} m_e v^2 = \frac{1}{2} m_e {v_e}^2 + \frac{1}{2} m_p {v_p}^2 \end{cases}$$

Since there is still a collision angle problem due to the interaction of the two particles, considering that the electrons inside the atom have better symmetry, only the frontal collision on the axis is considered here.

If the electron and proton collide head-on on the axis of the electron's movement, the velocity of the electron and proton before and after the collision is only have different sign, which is easier to calculate and can be calculated:

$$\mathbf{v}_e = \frac{(1-k)}{2}\mathbf{v}_p$$

Where：

$$\mathrm{k} = \frac{m_p}{m_e}$$

So after interaction, the relationship of energy that electron and proton possessed is：

$$\frac{1}{2}m_e {v_e}^2 = \frac{(1-k)^2}{4}\cdot\frac{1}{2}m_e {v_p}^2$$

Or

$$\frac{1}{2}m_e {v_e}^2 = \frac{(1-k)^2}{4}\cdot\frac{1}{2k}m_p {v_p}^2$$

That is

$$E_e = \frac{(1-k)^2}{4k}E_p \qquad (4)$$

Where E_e represents the kinetic energy of the electron after interaction and Ep represents the kinetic energy of the proton after the interaction. After the interaction, the energy lost by the electron is E_p, which has the following relationship

$$\eta = \frac{E_p}{E_0} = \frac{4k}{(1-k)^2+4} \qquad (5)$$

Here E_0 is the initial kinetic energy of the electron. It can be seen that the energy transferred from electron to proton is very small. Only the energy of the η ratio produces a shift. Consider the requirements of quantization in the micro world. There is only one virtual photon, so this energy transfer reflects the efficiency of electron emission or absorption virtual photons during the electron proton interaction.

It can also be proved that the energy efficiency from proton transfer to electrons is only η.

Therefore, the formula (5) reflects the interaction between particles of different masses, and an efficiency problem of the virtual photon exchange itself. If the two particles are of equal mass, then η = 1, that is, the efficiency of the virtual photon exchange is 100%. So according to the formula, takes into account the mass difference between the interacting particles, formula (1) and (2) becomes

$$j_{emittion} = \alpha \cdot \eta \quad (6)$$

$$j_{absorption} = \alpha \cdot \eta \quad (7)$$

Therefore

$$j = j_{emittion} = j_{absorption} = \alpha \cdot \eta \quad (8)$$

3 Lamb Shift

3.1The energy difference of Lamb shift

The Lamb shift reflects that the $2S^{1/2}$ and $2P^{1/2}$ orbits in the degenerate state of the energy level should have the same energy. However due to the difference in the orbital position, there is a slight difference between the two energy levels. This difference cannot be explained by the Schrödinger equation and the Dirac equation.

If we view the $2S^{1/2}$ and $2P^{1/2}$ orbitals from the perspective of the virtual photon, the main difference between the two is the difference in the number of virtual photons. For a hydrogen atom, there is only an electron and a proton, that is, only electrons and protons interact. Therefore, the exchange of virtual photons is limited to between electron and proton.

Different from the interaction between electron and electron, the mass difference between electron and proton is very large. So the energy exchange efficiency between different mass particles is relatively low. This can be seen from calculations of the collision of two different masses of particles in classical mechanics.

3.2 Using virtual photon theory to solve Lamb shift problem

Using the Schrödinger equation or the virtual photon wave function to solve the energy level of a hydrogen atom, a more accurate result can be obtained. However, when the energy level of an electron can accommodate multiple virtual photons, this will show a difference from the classical mechanical processing. These differences are mainly due to the fact that the wavelengths of the virtual photons will be different, which will affect the position of the virtual photons in the atoms, and the energy loss of electron in different orbit will also be different.

Intuitively, the virtual photon wavelength of the $2S^{1/2}$ orbit is shorter, which causes additional time for the virtual photon to pass from the orbit to the nucleus, which can reduce the energy lost by the interaction. There are two virtual photons in the $2P^{1/2}$ orbital with a longer virtual photon wavelength. Since the two virtual photons are all located in the center of nucleus, the virtual photon exchange efficiency is slightly high than the $2S^{1/2}$ orbital with only one virtual photon and a shorter virtual photon wavelength.

The reason we use the orbital spin angular momentum coupling results in the same is because only the two are comparable. Otherwise, we must consider the solution of the Dirac equation. For convenience, the 2S and 2P orbit described below also represents the $2S^{1/2}$ and $2P^{1/2}$ tracks actually.

3.2.1 The electron proton interactions in ground state

The energy ratio described in the analysis below is a statistical result. In fact, after each virtual photon exchange process is completed, the entire virtual photon is transferred from electron to proton or other electron. That is to say, there is always only one virtual photon in the entire atomic system.

For hydrogen atoms, considering the interaction between the electron and the proton, the probability of the electron emitting a photon to the proton is j, which is the probability of the electron losing energy. Therefore, the proportion of energy that the electron also have is

$$1 - \mathrm{j} \tag{9}$$

Although the virtual photons attached to the electron are emitted, one part of the emitting probability of the virtual photon is emitted out of the atom and the other part probability is absorbed by the proton and remains in the atom, which is part of the total energy of the atom. Considering that the probability of proton absorption of a virtual photon is also j, the probability that a proton obtains a virtual photon from an electron is j^2, so that after this round of virtual photon exchange, electron emit virtual photon, and proton absorb partial virtual photon. The remaining energy ratio of the entire system is

$$1 - \mathrm{j} + \mathrm{j}^2 \tag{10}$$

Then consider the probability of the virtual photon absorbed by the proton j^2. After the proton absorbs the virtual photon, there is a requirement to immediately emit the virtual photon. And the emission probability is j, so the total energy of the system will lose the energy of the ratio $\mathrm{j} \cdot \mathrm{j}^2$, that is, the total energy ratio that the system can retain is

$$1 - \mathrm{j} + \mathrm{j}^2 - \mathrm{j} \cdot \mathrm{j}^2 \tag{11}$$

Considering the energy lost in this part, the proportion of energy that can be absorbed by electron is $\mathrm{j}^2 \cdot \mathrm{j}^2$. Therefore, after the proton exchange virtual photon with the electron, the total energy ratio that the system can retain is

$$1 - \mathrm{j} + \mathrm{j}^2 - \mathrm{j}^3 + \mathrm{j}^4 \tag{12}$$

This loops continuously, we can get a sequence of numbers

$$\mathrm{p} = 1 - \mathrm{j} + \mathrm{j}^2 - \mathrm{j}^3 + \mathrm{j}^4 - \cdots = \frac{1}{1+j} \tag{13}$$

This is the total energy ratio that can be left after the two particles in the atom interact to exchange virtual photons.

For the 1S orbital of a hydrogen atom, after considering the virtual photon exchange energy loss between the electron and the proton, the total energy of hydrogen ground state becomes:

$$\mathrm{E} \approx -\frac{\mathrm{e}}{4\pi\varepsilon r} + \mu\mathrm{c}^2 + \frac{1}{2\mu}\left(\frac{h}{2\pi r}\right)^2 \frac{1}{1+j} \qquad (14)$$

The energy of the 1S energy level thus calculated will be:

$$E_{1S} = -\frac{1}{2}\left(\frac{e^2}{2\varepsilon hc}\right)^2 \mu c^2(1+j) = -\frac{1}{2}\alpha^2\mu c^2(1+j) \qquad (15)$$

It can be seen that for the ground state energy, if the effect of the virtual photon exchange is considered, the ground state energy of the hydrogen atom may be slightly lower than the results calculated by the Schrödinger equation. Of course, the reduced mass μ is used here, which also means that the difference in electron and proton mass has been considered. If the electron mass is reduced, this also means that the electric field is emitted by an infinite mass of the object. This calculation of the energy exchange probability j becomes more complicated. Therefore, the results obtained by the formula of (15) should still have errors.

3.2.2 Electron and Proton interaction in 2S orbit

If the virtual photon exchange is not considered, the total energy of the $2S^{1/2}$ orbit can be found as

$$\mathrm{E} \approx -\frac{\mathrm{e}^2}{4\pi\varepsilon r} + \mu\mathrm{c}^2 + \frac{1}{2\mu}\left(\frac{2h}{2\pi r}\right)^2 \qquad (16)$$

The energy of the $2S^{1/2}$ energy level thus calculated will be

$$E_2 = -\frac{1}{8}\alpha^2\mu c^2 \qquad (17)$$

Of which

$$\mathrm{r} = \frac{4\hbar}{\alpha\mu c} \qquad (18)$$

That is four times the Bohr radius.

The kinetic energy of electronics is

$$\mathrm{E}_k \approx \frac{1}{2\mu}\left(\frac{\alpha\mu c}{2}\right)^2 = \frac{\alpha^2\mu c^2}{8} \qquad (19)$$

Different from the 1S orbit, it can be seen from the calculations of the formulas (18) and (19) that the virtual photon wavelength of the $2S^{1/2}$ orbital is shorter than the distance of the electron from the proton. This also means that the electron wave function of the $2S^{1/2}$ orbital is mainly distributed on the spherical surface with radius r.

Of course, since the virtual photon carried by electron is farther away from the proton, the interaction between electron and proton is weaker, and the loss of electron energy caused by electron proton interaction is smaller than that of 2P orbital. It is very difficult to accurately find this loss. Quantum electrodynamics requires very complex calculations to get an accurate solution. For ease of understanding, here is a simple estimate of the impact of the characteristics of the 2S orbit on the virtual photon exchange.

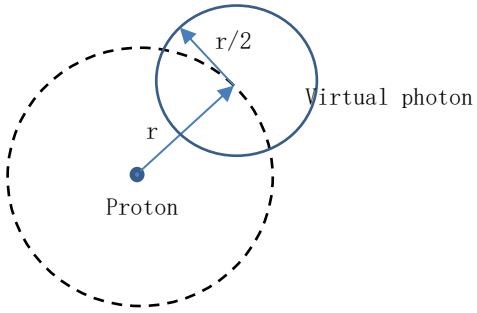

Fig. 3-5 The virtual photon location at hydrogen 2S orbit

Since the virtual photon wavelength is smaller than the orbital radius in the 2S orbit, the electron is already closer to the behavior of the classical particle. A virtual photon can be seen as directly attached to an electron. It can be seen from Fig. 3-5 that the distance from the proton in the center of the virtual photon of the $2S^{1/2}$ orbital of the hydrogen atom is r, and the orbital circumference is $2\pi r$. Note the symmetry, although the virtual photons shown in Fig. 3-5 are in the hydrogen atom, a certain moment exists in a certain direction, but the actual situation is that the virtual photon is isotropically distributed in the $2S^{1/2}$ orbit of the hydrogen atom, which can also be seen from the solution of the Schrödinger equation. Here, there is a problem whether r should be used to indicate the distance of the virtual photon transfer, or the orbital circumference $2\pi r$ is used to represent the distance of the virtual photon transfer. Taking into account the requirements of symmetry, the choice here is the circumference, which is the circumference of the orbit. For the 2P orbit, since the center of the virtual photon coincides with the nucleus, it means that the circumference of the orbit is zero, and the electron interacts directly with the proton, and there is no such a loss of energy loss as the $2S^{1/2}$ orbital.

Does this choice contradict with classic mechanics? Considering the circular motion of electron under macroscopic conditions, this isotropic requirement has been undermined. So the interaction between electron and proton is closer to colliding with two particles. This may reflect some differences between microscopic and macroscopic particles.

Therefore, compared with the $2P^{1/2}$ orbit, the exchange of $2S^{1/2}$ orbital virtual photons requires a

transmission distance of 2πr. Since the virtual photon will exist in the form of photon after leaving the particle, its transmission speed is the speed of light c.

The time required is

$$t_1 = \frac{2\pi r}{c} \qquad (20)$$

In addition, the process of converting from a virtual photon to a photon takes time, which can be estimated by the uncertainty principle. According to the uncertainty relationship between time and energy, it means that the time required for the virtual photon of 2S energy to be converted into photons is at least:

$$|\mathrm{E}_2||\Delta t| = \frac{\hbar}{2}$$

Where, the E_2 is the energy of the 2S orbit. The exchange of virtual photons involves both the release and absorption processes, and the time required is the same, so the total time required for virtual photon exchange between particles is

$$t_2 = 2|\Delta t| = \left|\frac{\hbar}{E_2}\right| = \frac{8\hbar}{\alpha^2\mu c^2} \qquad (21)$$

Since the 2S orbit requires additional virtual photon transfer time, the ratio of additional electron proton interactions can be reflected by the proportion of time represented by (22). Which is

$$\Delta \mathrm{j}_{2s} = \frac{t_1}{t_1 + t_2}\alpha\eta \qquad (22)$$

Here, the $\alpha\eta$ is the probability of virtual photon exchange after the interaction distance effect is not considered.

Considering j_{2s} is very smaller, therefore, the r calculated by (20) can be solved by r calculated by (18).

Substituting (18) into (3-20), (21), (22) gives

$$\Delta \mathrm{j}_{2s} = \frac{\frac{8\pi\hbar}{\alpha\mu c^2}}{\frac{8\hbar}{\alpha^2\mu c^2} + \frac{8\pi\hbar}{\alpha\mu c^2}}\alpha\eta \approx \pi\alpha^2\eta \qquad (23)$$

The formula (23) reflects the decrease in the probability of virtual photon exchange after considering the virtual photon needs to transmit an additional distance in the 2S orbit. It can be seen that when t_1 is very large, $\Delta \mathrm{j}_{2s} \approx \alpha\eta$

This reflects the entire virtual photon exchange probability. So formula (8) becomes

$$j_{2s} = \alpha\eta - \pi\alpha^2\eta$$

Similar to the solution method of the 1S orbit, the total energy of the 2S orbit can be found as

$$\mathrm{E} \approx -\frac{\mathrm{e}^2}{4\pi\varepsilon r} + \mu\mathrm{c}^2 + \frac{1}{2\mu}\left(\frac{2h}{2\pi r}\right)^2 \frac{1}{1+j_{2s}} \qquad (24)$$

The energy of the 2S energy level thus calculated will be

$$E_{2S} = -\frac{1}{8}\alpha^2\mu c^2(1+j_{2s}) = -\frac{1}{8}\alpha^2\mu c^2(1+\alpha\eta-\pi\alpha^2\eta) \qquad (25)$$

3.2.3 Electron and Proton interaction in 2P orbit

For $2P^{1/2}$ orbits, if two virtual photons need to be exchanged, the energy of the electrons can be divided into two halves. Every half of the energy emits and absorbs a virtual photon. The proportion of energy that can be retained after a virtual photon is emitted is

$$\frac{E'}{2} = \frac{E}{2}\left(1-\mathrm{j}_p\right)$$

When this virtual photon is absorbed by another particle, the total energy ratio after absorption is

$$\frac{E'}{2} = \frac{E}{2}\left(1-\mathrm{j}_p+\mathrm{j}_p{}^2\right)$$

According to the calculation method of a single virtual photon exchange, it can be seen that the total energy ratio that can be retained after exchanging one of the virtual photons is

$$\frac{E'}{2} = \frac{E}{2}\left(1-\mathrm{j}_p+\mathrm{j}_p{}^2-\mathrm{j}_p{}^3+\mathrm{j}_p{}^4+\cdots\right)$$

Looking at the other half of the energy exchange for another virtual photon can also lead to the same conclusion. Since the exchange of these two virtual photons is independent of each other, this can be simply added, so that

$$E' = E\left(1-\mathrm{j}_p+\mathrm{j}_p{}^2-\mathrm{j}_p{}^3+\mathrm{j}_p{}^4+\cdots\right) \qquad (26)$$

This is consistent with the results obtained from the 1S orbit. By replacing the total energy ratio in equation (14) with the formula (26), the energy of the 2P orbital of the hydrogen atom can be determined as

$$E_{2P} = -\frac{1}{8}\alpha^2\mu c^2\left(1 + \mathrm{j}_p\right)$$

Because the virtual photon wavelength of the 2P orbit is consistent with the orbital radius, the virtual photon distribution of the 2P orbit is consistent with the virtual photon distribution of the 1S orbit, and its center coincides with the nucleus. In this way, the 2P orbit does not need to additionally consider that there is a non-zero distance between the virtual photon center and the nucleus to make the efficiency of virtual photon exchange is reduced. So

$$\mathrm{j_p} = \mathrm{j} = \alpha\eta$$

Therefor

$$E_{2P} = -\frac{1}{8}\alpha^2\mu c^2(1 + \alpha\eta) \qquad (27)$$

3.3 Estimate the Lamb shift between 2S and 2P orbit

Thus, according to the formulas (25) and (27), the energy difference between the 2S orbital and the 2P orbital of the hydrogen atom in the Lamb shift can be determined as

$$\Delta E = E_{2S} - E_{2P} = E_2\left(1 + j_{2s} - 1 - \mathrm{j}_p\right)$$

That is

$$\Delta E = -E_2 \cdot \pi\alpha^2\eta = \frac{1}{8}\alpha^2\mu c^2 \cdot \pi\alpha^2\eta \qquad (28)$$

Where E_2 is the energy of n=2 level of the hydrogen atom solved by the Schrödinger equation, that is, the energy represented by the formula (17).

Considering $m_p \gg m_e$, we have

$$\eta = \frac{4k}{(1-k)^2 + 4} \approx \frac{4m_e}{m_p}$$

And according to the hydrogen atom energy level data

$$E_2 = -82259.158cm^{-1}$$

Substituting other relevant data, we can get

$$\Delta E = 0.03cm^{-1} \qquad (29)$$

The sign is positive, indicating that the $2S^{1/2}$ level is higher than the $2P^{1/2}$ level.

According to the spectral data provided by nist.gov, the difference between the $2S^{1/2}$ and $2P^{1/2}$ orbital levels of hydrogen atoms is:

$$\Delta E = 0.035285982 cm^{-1} \qquad (30)$$

It can be seen that the estimated results (29) are consistent with the experimental data (30) on the order of magnitude.

4 Discussion

The use of virtual photons can solve some problems that quantum mechanics can not solve, which shows that the hypothesis of virtual photons has a solid theoretical and experimental basis. Theoretically, the virtual photons themselves have been widely used in quantum field theory, especially in the Feynman Diagram, virtual photons are an indispensable particle to describe electromagnetic interaction. Because the various processes of quantum field theory have been verified by enough experiments data, the existence of virtual photons as a microscopic particle is also based on a solid experiment.

So virtual photons are not a fake particle introduced only for ease of calculation. However, to obtain support in theory, only the existing physical theories such as quantum mechanics and quantum field theory are not enough, which is also an important reason why virtual photons have been present in various physical theories with a virtual particle. The establishment of virtual space-time Maxwell equations provides a better theoretical support for virtual photons.

Virtual photons can be applied to solve various practical problems, and in turn provide experimental support for the theory of Maxwell equations based on virtual space time. The application of virtual photon theory to solve the three-body problem of helium atom ground state energy has been a remarkable success. At present, the ground state energy of helium atom calculated theoretically conforms to the very high precision of the experimental value. In this paper, the virtual photon theory is applied to lamb shift, and the results obtained are consistent with the experimental data at least in order of magnitude. Although some assumptions are involved, it is believed that these assumptions do not have more assumptions than those made by theories such as quantum electrodynamics.

More importantly, as a result of the greatly simplified calculation process, the meaning of lamb shift has become clearer, which is conducive to the further development and application of the theory.

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Appendix: Chinese Version

用虚光子来估算兰姆移动的数值

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摘要：利用虚光子可以计算氢原子和氦原子的基态能级，计算方法比较简单，比较容易理解。而兰姆移动则是属于量子电动力学中的问题。要解释兰姆移动的成因，需要比较复杂的计算和各种假设。考验到氢原子 $2S^{1/2}$ 轨道和 $2P^{1/2}$ 轨道有明显的区别，其中涉及到电子和质子之间的虚光子交换，必然会引起虚光子交换方式的不同。这种虚光子交换方式的区别，可能引起 $2S^{1/2}$ 轨道和 $2P^{1/2}$ 轨道电子质子相互作用损失的能量也会有所区别。通过本文的计算发现，如果考虑到 $2S^{1/2}$ 轨道虚光子交换需要额外传输更长的距离，将导致虚光子能量交换的效率略有降低。这样 $2S^{1/2}$ 轨道损失的能量就会比 $2P^{1/2}$ 轨道损失的能量要小一些。这个能量差，反映的就是兰姆移动。计算结果与实验结果在数量级上是一致的。这说明兰姆移动也可能是由粒子之间虚光子交换效率的变化所引起的。

关键词：虚光子；兰姆移动；精细结构常数

1 Introduction

在2012年我提出了基于虚时空的麦克斯韦方程组[1,2]，对已有的麦克斯韦方程组进行了改进。随后我用新的麦克斯韦方程组的一个解，找出了虚光子的解[2,3]。

与光子对应的电磁波解不同，虚光子的解跨越了两个时空[2,3]。其中一部分位于虚时空中。因此如果两个粒子相互作用将导致虚光子的交换。这种虚光子能否交换的几率与粒子虚实时空能量紧密联系在一起。

按照粒子相互作用本质上就是虚光子交换这一思路，我对氦原子基态能量进行了精确求解[2,4]。求解的结果与实验结果非常接近。这在一定程度上证实了虚光子存在的合理性。

经过这几年的思考，我发现，虚光子的存在也有助于以更简洁的方式来解释兰姆移动——这种量子力学无法解释，而量子电动力学有需要非常复杂的假设才能进行解释的问题。

2 虚光子传递的几率

2.1 电磁场虚光子交换几率

在计算氦原子基态能级的时候，我假设了对于电磁相互作用，粒子发射或者吸收虚光子的几

率为α. 不过在这篇文章中我并没有给出原因。随着我对虚光子性质的逐步深入了解，这里尝试解释一下虚光子交换几率为α的来历。

虚光子本质上也是电磁波，因此虚光子的传递跟电磁场的性质有密切的联系。与普通光子对应的电磁波不同，由虚光子波动方程求解出来的虚光子波函数还包含了虚时空的空间位置[3]。因此探讨虚光子的交换必然也要涉及到虚时空的一些重要性质。

从虚时空和实时空的麦克斯韦方程组来看，广义磁荷与广义电荷并不是相等的。按照文献[1,2]的计算结果来看，广义磁荷比广义电荷要大，广义磁荷大约是广义电荷的 137 倍。这也意味着对于一个粒子而言，实时空的电磁场能量大约占到虚实时空电磁场总能量的 1/137. 因此可以看出在实时空产生电磁相互作用，只涉及到总能量的 1/137。这也说明实时空的电场要把能量释放出去或吸收进来的几率是大约 1/137，也就是精细结构常数 α. 即：

$$j_{释放虚光子} = \alpha \qquad (1)$$

由于虚光子属于这样的电磁场能量，公式（1）也可以应用到虚光子的传递。即一个静止质量不为 0 的粒子，其释放虚光子的几率为精细结构常数。同样对于虚光子的吸收也一样有：

$$j_{吸收虚光子} = \alpha \qquad (2)$$

虽然这不能算是一个严密的推导过程，但物质变化有自己的规律。因此一个结论如果能够被实验所证实，也就说明我们现在的理论分析还存在局限性。后面将给出一些实例对此结论进行分析。由于电磁相互作用的对称性要求，一般都有释放光子和吸收光子的概率是一样的，这样就有：

$$j = j_{释放虚光子} = j_{吸收虚光子} = \alpha \qquad (3)$$

2.2 两个不同质量粒子相互作用的虚光子传递效率

如果两个相互作用的粒子质量不同，则会影响到虚光子的传递效率。毕竟两个质量相等的粒子相互作用与两个质量相差非常大的粒子之间相互作用，二者的计算结果在经典力学上是有非常大的区别的。

这里先从经典力学的角度来分析电子与质子之间的相互作用。假设电子质量为 m_e，质子质量为 m_p，电子的初速度为 v，电子初始动能为$E_0 = \frac{1}{2}m_e v^2$，碰撞之后的速度为 v_e，电子碰撞之后动能为$E_e = \frac{1}{2}m_e {v_e}^2$；质子的初速度为 0，而碰撞之后的速度为 v_p，质子碰撞之后动能为$E_p = \frac{1}{2}m_p {v_p}^2$. 则按照动量守恒和能量守恒定律，有下面的关系（为简便，黑体表示矢量，斜体字母表示对应的标量）：

$$\begin{cases} m_e\mathbf{v} = m_e\mathbf{v}_e + m_p\mathbf{v}_p \\ \frac{1}{2}m_e v^2 = \frac{1}{2}m_e {v_e}^2 + \frac{1}{2}m_p {v_p}^2 \end{cases}$$

由于两个粒子相互作用还存在一个碰撞角度问题，不过考虑到原子内部的电子都具有比较好的对称性，因此这里只考虑轴线上的正面碰撞。

如果电子和质子在电子运行的轴线上正面碰撞，则碰撞前后电子和质子的速度只有正负号的区分，这种情况比较容易计算，可以计算出：

$$\mathbf{v}_e = \frac{(1-k)}{2}\mathbf{v}_p$$

其中：

$$\mathrm{k} = \frac{m_p}{m_e}$$

因此相互作用之后，电子与质子拥有的能量之间的关系为：

$$\frac{1}{2}m_e {v_e}^2 = \frac{(1-k)^2}{4}\cdot\frac{1}{2}m_e {v_p}^2$$

或者：

$$\frac{1}{2}m_e {v_e}^2 = \frac{(1-k)^2}{4}\cdot\frac{1}{2k}m_p {v_p}^2$$

即：

$$E_e = \frac{(1-k)^2}{4k}E_p \qquad (4)$$

其中 E_e 表示相互作用之后电子的动能，E_p 表示相互作用之后质子的动能。而相互作用之后，电子损失的能量就是 E_p，有下面的关系：

$$\eta = \frac{E_p}{E_0} = \frac{4k}{(1-k)^2+4} \qquad (5)$$

其中E_0为电子的初始动能。可以看出，从电子转移给质子的能量是非常小的。只有η比例的能量产生转移。考虑到在微观世界量子化的要求。虚光子只有一个，因此这样的能量转移反映出电子质子相互作用过程中，电子发射或吸收的效率。

同样也可以证明，从质子转移到电子的能量效率也只有η

因此公式（5）反映出不同质量的粒子之间相互作用，虚光子交换本身的一个效率问题。如果两个粒子质量相等，则$\eta = 1$，即虚光子交换的效率 100%，这样就可以按照公式，则虚光子在考虑到相互作用的粒子之间质量差异之后，公式（1）和（2）就变成了：

$$j_{释放虚光子} = \alpha \cdot \eta \qquad (6)$$

$$j_{吸收虚光子} = \alpha \cdot \eta \qquad (7)$$

因此有：

$$j = j_{释放虚光子} = j_{吸收虚光子} = \alpha \cdot \eta \qquad (8)$$

3 兰姆移动

3. 1 兰姆移动的能级差异

兰姆移动反映的是处于能级简并状态的 $2S^{1/2}$ 和 $2P^{1/2}$ 轨道本来能量应该是相同的，但是由于轨道位置的不同，导致这两个能级出现了很微小的差异。这种差异无法用薛定谔方程以及狄拉克方程来进行解释。

从虚光子的角度来看待 $2S^{1/2}$ 和 $2P^{1/2}$ 轨道，二者的主要区别在于虚光子数量的不同。而对于氢原子来说，只有电子和一个质子，即只有电子和质子之间产生相互作用。因此虚光子的交换也仅限于电子与质子之间。

同电子与电子之间的相互作用不同，电子与质子之间的质量差距非常大，因此不同质量粒子之间的相互能量交换效率也就比较低。这可以从经典力学两个不同质量的粒子相互碰撞看出来。

3.2 用虚光子求解兰姆移动频移

利用薛定谔方程或者虚光子波函数来求解氢原子的能级，可以获得比较准确的结果。然而当电子的能级可能容纳多个虚光子的时候，这时候就会显示出与经典力学处理问题不太相同的地方。这些差异主要源自虚光子的波长会不同，这会影响到虚光子在原子中所处的位置，从而导致电子-质子系统因此而损失的能量也会不尽相同。

直观上来看，$2S^{1/2}$ 轨道的虚光子波长更短，导致虚光子从轨道传递到原子核需要消耗额外的时间，这能够减少相互作用而损失的能量。这也意味着拥有两个虚光子，且虚光子波长更

长的 $2P^{1/2}$ 轨道要比只有一个虚光子且虚光子波长更短的 $2S^{1/2}$ 轨道能级会略低一些。

之所以是轨道自旋角动量耦合结果相同的轨道，是因为只有这样二者才有可比性。否则就要考虑狄拉克方程的求解结果。为了方便，下面所说的 2S 和 2P 轨道都是表示 $2S^{1/2}$ 和 $2P^{1/2}$ 轨道。

3.2.1 基态电子与质子之间的相互作用

下面的分析过程所说的能量比例，是一个统计的结果。而实际上，每次虚光子交换完成之后，整个虚光子就从电子传递到了质子或电子里面了。也就是说整个原子系统中始终只有一个虚光子。

对于氢原子，考虑电子与质子之间的相互作用，电子向质子发射虚光子的几率为 j，这是电子损失能量的几率。因此电子还拥有的能量比例为：

$$1 - j \tag{9}$$

虽然附着在电子上的虚光子发射出去了，一部分被发射出原子，而另一部分则被质子吸收，仍然保留在原子中，属于原子总能量的一个部分。考虑到质子吸收虚光子的几率也为 j，这样质子从电子处获得虚光子的几率为j^2，这样经过这一轮虚光子交换过程，即电子发射虚光子，而质子吸收部分虚光子，整个系统还剩下的能量比例为：

$$1 - j + j^2 \tag{10}$$

然后考虑质子吸收到的虚光子几率j^2，在质子吸收到了虚光子之后，又存在马上将虚光子发射出去的要求。且发射概率为 j，因此系统总动能中将损失$j \cdot j^2$比例的能量，即系统能够保留的总能量比例为：

$$1 - j + j^2 - j \cdot j^2 \tag{11}$$

再考虑这部分损失的能量中，能够被电子吸收的能量比例为$j^2 \cdot j^2$，因此经过质子向电子交换虚光子之后，系统还能够保留的总能量比例为：

$$1 - j + j^2 - j^3 + j^4 \tag{12}$$

这样不断循环，我们就可以获得一个数列：

$$p = 1 - j + j^2 - j^3 + j^4 - \cdots = \frac{1}{1+j} \tag{13}$$

这就是原子中两个粒子相互作用交换虚光子后，还能够剩下的总能量比例。

对于氢原子 1S 轨道，考虑到电子和质子之间的虚光子交换能量损失之后，氢原子基态的总能量就变成了：

$$\mathrm{E} \approx -\frac{\mathrm{e}}{4\pi\varepsilon r} + \mu\mathrm{c}^2 + \frac{1}{2\mu}\left(\frac{h}{2\pi r}\right)^2 \frac{1}{1+j} \qquad (14)$$

这样计算出来的 1S 能级的能量将为：

$$E_{1S} = -\frac{1}{2}\left(\frac{e^2}{2\varepsilon hc}\right)^2 \mu c^2(1+j) = -\frac{1}{2}\alpha^2\mu c^2(1+j) \qquad (15)$$

可以看出对于基态能量，如果考虑了虚光子交换的作用，则氢原子基态能量可能要比薛定谔方程计算出来的结果略微低一些。当然这里使用的是约化质量μ，这也意味着已经考虑了电子和质子质量的不同，如果电子质量为约化质量，则这也意味着电场由一个无穷大质量的物体发出。这样能量转移几率 j 的计算会变得比较复杂。故（15）的公式获得的结果应该仍然会有误差的出现。

3.2.2 2S 轨道电子与质子的相互作用

如果不考虑虚光子交换，可以求出 2S 轨道的总能量为：

$$\mathrm{E} \approx -\frac{\mathrm{e}^2}{4\pi\varepsilon r} + \mu\mathrm{c}^2 + \frac{1}{2\mu}\left(\frac{2h}{2\pi r}\right)^2 \qquad (16)$$

这样计算出来的 2S 能级的能量将为：

$$E_2 = -\frac{1}{8}\alpha^2\mu c^2 \qquad (17)$$

则其中的

$$\mathrm{r} = \frac{4\hbar}{\alpha\mu c} \qquad (18)$$

也就是四倍的玻尔半径。

而电子所具备的动能为：

$$\mathrm{E}_k \approx \frac{1}{2\mu}\left(\frac{\alpha\mu c}{2}\right)^2 = \frac{\alpha^2\mu c^2}{8} \qquad (19)$$

与 1S 轨道不同，通过公式（18 和（19）的计算可以看出，2S 轨道的虚光子波长比电子离质子的距离要短。这也意味着 2S 轨道的电子波函数主要分布在以 r 为半径的球面上。

当然由于电子所携带的虚光子离质子的距离更远了，电子与质子的相互作用就会弱一些，电子质子相互作用导致的电子能量的损失会比 2P 轨道要小一些。要精确求出这个损失是很困难的。量子电动力学需要经过非常复杂的计算才能获得精确解。为便于理解，这里简单估算一下 2S 轨道的特点对虚光子交换的影响。

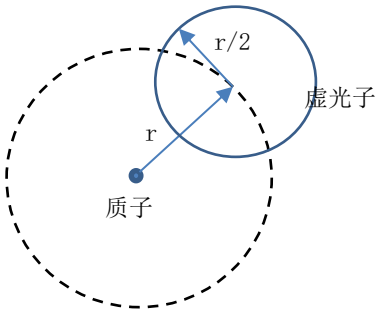

图 3-5 氢原子 2S 轨道虚光子的位置

由于在 2S 轨道中，虚光子波长比轨道半径要小，因此电子已经比较接近经典粒子的行为。虚光子可以视为直接附着在电子上面。从图 3-5 可以看出，在氢原子 2S 轨道虚光子中心位置距离质子的距离为 r，轨道周长为 2πr. 注意到对称性，虽然图 3-5 表示的虚光子在氢原子中在某个时刻存在与某个方向上，但实际情况则是虚光子是各向同性地分布在氢原子 2S 轨道上的，这也可以从薛定谔方程的求解结果看出来。这里就存在一个应该使用 r 来表示虚光子传递的距离，还是用轨道周长2πr来表示虚光子传递的距离问题。考虑到对称性的要求，这里选择的是周长，也就是轨道的周长。对于 2P 轨道，由于虚光子的中心与原子核重合，意味着轨道的周长为 0，电子与质子直接相互作用，没有因为 2S 轨道那样的能量损失减少的情况出现。

这样的选择是否与经典力学存在矛盾？考虑到宏观条件下电子的圆周运动已经破坏了这种各向同性的要求。因此电子与质子之间的相互作用已经更接近与两个粒子碰撞了。这也许反映出微观粒子与宏观粒子之间的一些区别。

因此同 2P 轨道相比，2S 轨道虚光子的交换需要多传输2πr的距离。由于虚光子离开粒子后将以光子的形式存在，因此其传输的速度为光速 c.

所需时间即为：

$$t_1 = \frac{2\pi r}{c} \tag{20}$$

另外从虚光子转换成光子的过程也需要时间，这一时间可以由不确定性原理来进行估算。按照时间和能量的不确定性关系，意味着 2S 能量的虚光子要转换成光子所需时间至少为：

$$|\mathrm{E}_2||\Delta t| = \frac{\hbar}{2}$$

其中 E_2 为 2S 能级的能量。虚光子的交换包括了释放和吸收两个过程，所需的时间都是一样的，因此粒子之间虚光子交换所需的总时间为：

$$t_2 = 2|\Delta t| = \left|\frac{\hbar}{E_2}\right| = \frac{8\hbar}{\alpha^2 \mu c^2} \tag{21}$$

鉴于 2S 轨道需要额外的虚光子传输时间，额外的电子质子相互作用减弱的比例可以用（22）所表示的时间比例来反映出来。即：

$$\Delta \mathrm{j}_{2s} = \frac{t_1}{t_1 + t_2} \alpha\eta \qquad (22)$$

其中αη是不考虑相互作用距离效应之后的虚光子交换几率。

考虑到j_{2s}非常小，因此可以（18）所计算出来的 r 来求解（20）式所表示的 t_1.

将（18）代入（20）、（21）、（22）可以得到：

$$\Delta \mathrm{j}_{2s} = \frac{\frac{8\pi\hbar}{\alpha\mu c^2}}{\frac{8\hbar}{\alpha^2\mu c^2} + \frac{8\pi\hbar}{\alpha\mu c^2}} \alpha\eta \approx \pi\alpha^2\eta \qquad (23)$$

公式（23）反映的是 2S 轨道中，考虑到虚光子需要额外传递一个距离以后，虚光子交换几率的减少值。可以看出当 t_1 非常大的时候，$\Delta \mathrm{j}_{2s} \approx \alpha\eta$

这样反映整个虚光子交换几率公式(8)就变成了：

$$j_{2s} = \alpha\eta - \pi\alpha^2\eta$$

与 1S 轨道的求解方法类似，可以求出 2S 轨道的总能量为：

$$\mathrm{E} \approx -\frac{\mathrm{e}^2}{4\pi\varepsilon r} + \mu\mathrm{c}^2 + \frac{1}{2\mu}\left(\frac{2h}{2\pi r}\right)^2 \frac{1}{1 + j_{2s}} \qquad (24)$$

这样计算出来的 2S 能级的能量将为：

$$E_{2S} = -\frac{1}{8}\alpha^2\mu c^2(1 + j_{2s}) = -\frac{1}{8}\alpha^2\mu c^2(1 + \alpha\eta - \pi\alpha^2\eta) \qquad (25)$$

3.2.3 2P 轨道电子与质子的相互作用

对于 2P 轨道，有两个虚光子需要交换，则可以将电子的能量分成两半来考虑。每一半能量发射和吸收一个虚光子。这样在发射一个虚光子之后还能保留的能量比例为：

$$\frac{E'}{2} = \frac{E}{2}\left(1 - \mathrm{j}_p\right)$$

这个虚光子又被另一个粒子所吸收，则吸收后的总能量比例为：

$$\frac{E'}{2}=\frac{E}{2}\left(1-\mathrm{j}_p+{\mathrm{j}_p}^2\right)$$

按单个虚光子交换的计算方法，可以看出交换其中一个虚光子后还能够保留的总能量比例为：

$$\frac{E'}{2}=\frac{E}{2}\left(1-\mathrm{j}_p+{\mathrm{j}_p}^2-{\mathrm{j}_p}^3+{\mathrm{j}_p}^4+\cdots\right)$$

再看另一半能量交换另一个虚光子，也可以得出相同的结论。由于这两个虚光子的交换是相互独立的，因此而这可以简单相加，这样可以得到：

$$E'=E\left(1-\mathrm{j}_p+{\mathrm{j}_p}^2-{\mathrm{j}_p}^3+{\mathrm{j}_p}^4+\cdots\right) \qquad (26)$$

这与 1S 轨道求出的结果形式上是一致的。用公式(26)替换公式（14）中的总能量比例，则可以求出氢原子 2P 轨道的能量为：

$$E_{2P}=-\frac{1}{8}\alpha^2\mu c^2\left(1+\mathrm{j}_p\right)$$

因为 2P 轨道的虚光子波长与轨道半径是一致的，因此 2P 轨道的虚光子分布与 1S 轨道的虚光子分布是一致的，其中心与原子核重合。这样 2P 轨道就不需要额外考虑虚光子中心与原子核之间存在一个非 0 的距离，而导致虚光子交换的效率有所降低。这样：

$$\mathrm{j_p}=\mathrm{j}=\alpha\eta$$

因此：

$$E_{2P}=-\frac{1}{8}\alpha^2\mu c^2(1+\alpha\eta) \qquad (27)$$

3.3 2S 和 2P 轨道兰姆移动能量

这样根据公式（25）和（27），就可以求出兰姆移动中的氢原子 2S 轨道和 2P 轨道的能量差为：

$$\Delta E=E_{2S}-E_{2P}=E_2\left(1+j_{2s}-1-\mathrm{j}_p\right)$$

即：

$$\Delta E=-E_2\cdot\pi\alpha^2\eta=\frac{1}{8}\alpha^2\mu c^2\cdot\pi\alpha^2\eta \qquad (28)$$

其中E_2为薛定谔方程求解出来的氢原子 n=2 的能级能量，即公式（17）所表示的能量。

考虑到$m_p\gg m_e$，有：

$$\eta = \frac{4k}{(1-k)^2+4} \approx \frac{4m_e}{m_p}$$

而根据氢原子能级数据：

$$E_2 = -82259.158cm^{-1}$$

代入其他相关的数据，可以得到：

$$\Delta E = 0.03cm^{-1} \qquad (29)$$

符号为正，说明 $2S^{1/2}$ 能级比 $2P^{1/2}$ 能级要高一些。

根据 nist.gov 提供的光谱数据，氢原子 $2S^{1/2}$ 和 $2S^{1/2}$ 轨道能级的差值为：

$$\Delta E = 0.035285982cm^{-1} \qquad (30)$$

可以看出估算的结果（29）与实验数据（30）在数量级上还是一致的。

4 讨论

利用虚光子能够求解一些量子力学不能够解决的问题，这说明虚光子的假设有比较坚实的理论和实验基础。从理论上来看，虚光子本身在量子场论中已经得到了广泛的应用，特别是在费因曼图中，虚光子是描述电磁相互作用不可缺少的一种粒子。由于量子场论的各种过程都已经获得了足够的实验验证，虚光子这种微观粒子的存在也是有坚实的实验基础的。因此虚光子并不是一个为了计算方便而引入的假象的粒子。

然而要在理论上获得支持，仅有量子力学和量子场论等已有的物理理论还是不够的，这也是虚光子一直以一种假想的粒子而存在于各种物理理论中的重要原因。虚时空麦克斯韦方程组的建立，为虚光子提供了比较好的理论支持。而虚光子能够被应用解决各种实际问题，又反过来为虚时空麦克斯韦方程组的理论提供了实验方面的支持。

应用虚光子理论来解决氦原子基态能量这样的三体问题已经获得了显著的成功。目前理论计算出来的氦原子基态能量与实验值在非常高的精度上相符合。本文将虚光子理论应用到兰姆移动上，获得的结果至少在数量级上是与实验数据相符合的。尽管其中涉及到一些假设，但相信这些假设并不会比量子电动力学等理论所提出的假设更多。更为重要的是，由于大为简化了计算过程，兰姆移动的含义也变得更加清晰，这是有助于理论的进一步发展和应用的。

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