More accurate analysis of redshift caused by photon neutrino interaction

Zhi Cheng
9 Bairong st. Baiyun District, Guangzhou, China. 510400. gzchengzhi@hotmail.com

Abstract: In experiments on gravitational redshift in the past, there were many additional redshifts that could not be explained by known theories. In 1990, Potzel used the higher-precision Mössbauer effect to verify the gravitational redshift, and found additional redshift data that could not be explained by existing theories. I assume that these extra redshifts are caused by photon neutrino interactions. On the basis of this, through the further analysis of the results of the Potzel experiment, a more accurate spectral redshift value caused by photon neutrino interaction is obtained. At the same time, the analysis results are used to explain the extra solar redshift of the 500 nm spectrum at the limb. These extra redshift values also exceed the value of the theoretical gravitational redshift and cannot be explained by other reasons. The results of this paper show that the redshift caused by the photon neutrino interaction is in good agreement with the actual observation compared to other hypotheses.

Key words: Mössbauer effect; photon; neutrino; red shift

1 Introductions

In my recent research, I found that there may be interactions between photons and neutrinos [1~2], which are beyond the scope of weak interactions. If such a photon neutrino interaction exists, it will help us use a lighter device to detect neutrinos, and the results are more direct.

In paper [2], by analyzing the redshift of the distant galaxies and the data of the gravitational redshift experiment conducted by Pound in 1960 [3], the estimation of the magnitude of redshift caused by photon neutrino interaction is obtained. The main problem of such analysis is that the data accuracy is not high. In the experimental data of Pound, the systematic error caused by other factors cannot be effectively excluded.

This article attempts to analyze more accurate experimental data. Potzel also uses the Mössbauer effect to measure the gravitational redshift [4], but its accuracy is higher, and a reference absorber is also used for comparison, which can effectively reduce the existence of systematic errors.

In addition, the solar spectrum redshift at the limb [5~6] is also an important evidence because of the existence of additional redshifts that cannot be explained by gravitational redshift and other known factors. If the photon neutrino interaction can be used to successfully interpret this part of the extra redshift, it will help to confirm the intensity of the photon neutrino interaction and what kind of precision experimental equipment is needed on the earth..

2 The analysis of Potzel's experimental data

Unlike Pound's 1960 experiment, Potzel uses a higher energy ^{67}Zn, and the gamma ray energy emitted by the source can reach 93.31kev, so the accuracy can be increased by about 6 times.

Another feature of Pound's experiment is the use of a reference absorber that is close to the source as the center of the frequency shift, which can better reduce the systematic error in the experiment. The existence of systematic errors that cannot be explained by existing theories has also been discovered.

First, we do not consider the existence of systematic errors. Since the reference absorber and the experimental absorber are at different distances from the source, the reference absorber is very close to the source but still has a small distance. Therefore, when the experimental device is reversed from the test redshift state to the test blue shift state, there is still a small movement of the reference absorber. The errors produced by this device state change were ignored in Potzel's experiments. However, considering the red shift or blue shift phenomenon caused by gravity, the influence of other factors on the spectrum, this time the frequency shift of this part of the spectrum can be considered. Of course, since the experiment is not designed to test such frequency shifts, the relative error of the obtained data will be relatively large, but its magnitude is still have some reference value.

Table 1 ^{67}Zn Mössbauer effect measurement data (Potzel 1992) [4]

Frequency shift type	Length (mm)	Equivalent gravity acceleration g(m/s2)	Errors
R	1010	12.1	0.4
R	1010	11.9	0.4
R	1010	12.8	0.6
R	1010	12.6	0.6
R	1005	11.6	0.5
R	985	12.9	0.4
R	1039	11.5	0.3
R	1039	11.7	0.4
R	1039	11.4	0.8
B	1039	11.3	0.5

In Table 1, the frequency shift type R represents a redshift and B represents a blue shift, and the length represents the distance between the experimental absorber and the reference absorber. Here, three data of 0.58 m length are deleted, because the difference in the length of the red and blue shift is large, and it is not suitable for comparison. The equivalent gravity acceleration represents the measured frequency shift, which is equivalent to the frequency shift caused by the theoretical calculation of the acceleration.

According to the data in Table 1, the average equivalent gravity acceleration corresponding to the red shift can be calculated to be 12.1±0.5.

There is only one blue shift data, and the corresponding equivalent gravity acceleration is 11.3±0.5.

This can be calculated that there is an equivalent acceleration difference between the red and blue shifts of 0.8 ±0.5

Theoretical calculations should not have such a difference, so this difference reflects the other non-gravitational factors. The sign is positive, indicating that this extra frequency shift is a redshift effect.

Calculated according to the standard gravity acceleration of 9.8, this additional redshift effect is approximately 4% of the gravitational redshift data per meter on the earth.

Second, consider the extra redshift caused by systematic errors that cannot be explained by the Potzel data itself.

In their article, Potzel carefully analyzed various possible factors that may cause these extra redshift data. After many exclusions, the data still has 6% error, and this error cannot be eliminated by technical means.

The red shift that occurs with this systematic error is different from the previous 4% additional red shift, which is the absolute error that occurs in the experimental equipment. The previous 4% extra redshift is the relative error of the data after the experimental device is inverted. Both data should be used to indicate the extra redshift that cannot be explained during the experiment. Therefore, an average redshift value of about 5% is taken here. This means that at least 5% of the extra redshifts in Potzel's experiments cannot be explained by existing theories. I assume here that there is an interaction of neutrinos with photons, and most of these extra redshifts should be caused by this photon neutrino interaction. In this way, the redshift caused by the photon neutrino interaction can be estimated to be approximately

$$\Delta z_b = \frac{\Delta f(b)}{f} \times 5\% = \frac{g}{c^2} \times 5\% = 5.5 \times 10^{-18}$$

Considering that the source energy of the Potzel experiment is 6.48 times that of the Pound experimental source, the accuracy will be higher, so this data is more accurate than the estimation in paper [2]. Although the frequency shift is small, it can still be measured within the accuracy of the existing Mössbauer experiment. If we can increase the distance between the source and the absorber, use a higher energy source, and measure in a higher concentration of neutrino environment, the results may be more accurate.

3 Extra solar redshift at the limb

Pecker proposed in 1972 that there might be an interaction between photon and photon. If such an interaction exists, it can be used to explain the solar redshift at the limb.

The solar redshift at the limb is part of the solar spectrum's Limb Effect. The limb effect of the solar spectrum refers to the phenomenon that the solar spectrum gradually redshifts from the center of the solar disk to the limb. The more you reach the limb, the greater the redshift. This cannot be completely explained by gravitational redshift.

For the interior of the disk, the factors involved are relatively complex, including gravitational redshift, including the frequency shift caused by ionized gas, Doppler Effect, and rotation effect. However, at the limb, it is completely unaffected by these other factors, that is, if there is a known theory that can explain the solar redshift at the limb, then this theory is the gravitational redshift.

However, Pecker pointed out [5] that the actual situation is that the solar redshift at limb is larger than the gravitational redshift calculated according to the general theory of relativity, which is about $2 \times 10^{-7} < \Delta z < 10^{-6}$ and the gravitational redshift calculated by relativity is about $z_g = 2.12 \times 10^{-6}$

Pecker hopes to explain this extra redshift by the mechanism of photon-photon interaction. However, their calculations show that the effect of photon-photon interaction may be much smaller than the calculated data of gravitational redshift [5]. Cohen also pointed out in 1973 [6] that based on some past experimental data, the photon-photon interaction is at least three orders of magnitude smaller than the gravitational redshift.

Therefore, the effect of photon-photon interaction on the solar redshift at the limb can be basically ruled out.

Here we consider the existence of photon-neutrino interactions. Using the results of the Potzel experiment, we can do the following analysis:

First, simply estimate it.

According to Potzel's experimental results, the extra redshift is about 5% of the gravitational redshift. According to this calculation, the 5% solar redshift value at the limb is about $\Delta z = 1.6 \times 10^{-7}$. This is roughly the same as the magnitude of the extra solar redshift at the limb.

Secondly, I also do a specific calculation.

Suppose the concentration of solar neutrinos on the surface of the earth is n(b)/m3, the radius of the sun is a, and the distance from the sun to the earth is b. Assuming that the total amount of neutrinos is constant, the solar surface neutrinos can be easily calculated. The concentration is

$$\mathrm{n(a)} = \mathrm{n(b)}\left(\frac{b}{a}\right)^2$$

The distance from the sun to r, where the concentration of the neutrino is

$$\mathrm{n(r)} = \mathrm{n}\left(\frac{b}{r}\right)^2 \qquad （1）$$

The unit length frequency shift caused by the interaction of neutrinos with photons with a concentration of n(b) on the surface of the Earth's surface is

$$\Delta z_b = \frac{\Delta \mathrm{f(b)}}{f} = \frac{\mathrm{kn(b)}}{f} \qquad （2）$$

Where k is a constant.

Then the unit length frequency shift caused by the photon neutrino interaction at the distance r from solar is

$$\Delta z_r = \frac{\Delta \mathrm{f(r)}}{f} = \frac{\mathrm{kn(b)}}{f}\left(\frac{b}{r}\right)^2 = \Delta \mathrm{z}_b\left(\frac{b}{r}\right)^2$$

Converting to the integral form gives the total energy lost by the photon from the limb of the solar disk to the surface of the Earth, i.e. the total redshift frequency of the spectrum

$$\Delta \mathrm{z} = \frac{\Delta \mathrm{f}}{f} = \int_a^b \frac{\mathrm{kn(b)}}{f}\left(\frac{b}{r}\right)^2 dr \qquad （3）$$

Substituting the solar radius and the distance from the sun to the Earth, and assuming that the photon passes through the path to continue to interact with all neutrinos, plus the upper limit of the redshift based on the Potzel experimental data, the total frequency shift can be calculated as

$$\Delta z = \frac{\Delta f}{f} = \Delta z_b \int_a^b \left(\frac{b}{r}\right)^2 dr = 1.65 \times 10^{-4} \qquad （4）$$

It can be noted that the frequency shift is too large, and is two orders of magnitude of the gravitational red shift. In fact, the energy loss of photons is not so much. There are two possible reasons for this:

1. Since this paper analyzes the Potzel experimental data to obtain a redshift upper limit, the red shift caused by the photon neutrino interaction is not as large as the redshift data that cannot be explained in the Potzel experiment. Nevertheless, the calculations also show that photon neutrino interaction is an important reason for causing additional red shift.

2. Photons can interact with solar-emitting neutrinos, but the number of interactions is not that much. There is a relationship between the actual number of neutrinos and the number of effective neutrinos that can interact with photons.

We consider the question of the number of effective neutrinos here.

Since neutrinos and solar photons are emitted simultaneously, the angle between the neutrino and the photon becomes very small at a position away from the sun.

Here is the assumption that one photon can only interact with the one neutrino in one time.

Considering that the photon itself has a wavelength, the neutrino will always interact with the photon in this wavelength range of the photon and in the direction of the photon flight. Therefore, if the collision angle of the neutrino and the photon is very small, it is very For a long time, although the number of neutrinos encountered in the path of photon travel is large, many other neutrinos do not interact with the photon.

To solve this problem, a concept of collision length is introduced here. That is, if one neutrino runs within a certain length and is likely to collide with one photon continuously, this length is called the collision length of the neutrino photon. As shown in Figure 1.

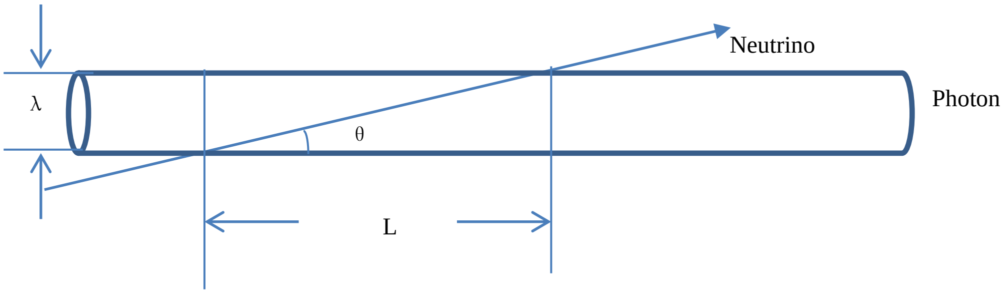

Figure 1. The neutrino photon collision length without considering the neutrino wavelength (λ indicates the wavelength of the photon, L is the collision length)

As can be seen from Figure 1, the collision length L is mainly determined by the angle between the photon and the neutrino. As long as the collision length L, this photon can only interact with this neutrino. However, other neutrinos located within the collision length will still be counted towards the neutrino density of the length through which the photon passes.

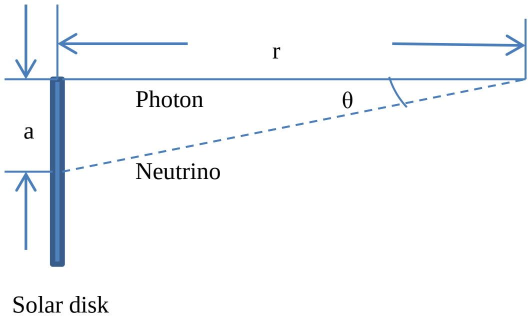

Figure 2. Relationship between photon neutrino collision point and the distance from solar disk

Figure 2 shows the distance between the photon neutrino collision point and the distance from solar disk. Here, to simplify the analysis process, the sun's surface is treated as a plane. Where a is the radius of the sun's surface, and the neutrino can be emitted from any position on the disk. The center position of the disk is calculated as the average of the neutrino emission position. r is the distance from the collision point to the disk limb. Combined with Figure 1 and Figure 2, the following formula can be derived

$$\frac{\lambda}{L} = \frac{a}{r}$$

That is

$$L = \frac{\lambda r}{a}$$

The presence of the length of the collision means that the neutrino is "bigger", and how many times it is larger means how many times the density of effective neutrinos that can interact with the photon is reduced.

It is assumed here that the wavelength of the neutrino itself is λ_v, the neutrino density on the earth's surface is n(b), and now the collision length is increased to $\lambda_v + L$, because the effective neutrino density is

$$n'(b) = \frac{\lambda_v}{\lambda_v + L_b} n(b)$$

Similarly, the relationship between the number of effective neutrinos and the actual number of neutrinos from the location of the Earth r is

$$n'(r) = \frac{\lambda_v}{\lambda_v + L_r} n(r)$$

So

$$n'(r) = \frac{\lambda_v}{\lambda_v + L_r} n(b) \frac{b^2}{r^2}$$

Note that Potzel et al.'s experiments used gamma rays instead of the solar rays emitted with neutrinos, which interact directly with photons, so the effective neutrino density in the Potzel experiment is n(b). It is $\Delta z_b = \frac{\Delta \mathrm{f(b)}}{f} = \frac{\mathrm{kn(b)}}{f}$

Then consider an approximate condition: $\mathrm{L} \gg \lambda_\nu$, substituting into formula (4), we can get:

$$\Delta \mathrm{z}_0 = \int_a^b \mathrm{kn}'(\mathrm{r})\mathrm{dr} = \Delta \mathrm{z}_b \int_a^b \left(\frac{b}{r}\right)^2 \frac{\lambda_\nu a}{\lambda r} dr = 8.3 \times 10^{-5} \frac{\lambda_\nu}{\lambda}$$

This mainly takes into account the position of L on the order of magnitude of λ_ν, which is basically located on the surface of the sun. Regardless of the length of the collision, only the magnitude of the red shift of the solar surface spectrum is very small, about 10^{-12}, which can be ignored.

Since the average energy of beta decay is about 300 keV, this can be seen as the average energy of the neutrinos released from the solar, corresponding to a wavelength of 4.1 nm, and the wavelength of the analyzed solar spectrum is 500 nm.

Therefore

$$\Delta \mathrm{z}_0 = 8.3 \times 10^{-5} \frac{\lambda_\nu}{\lambda} = 8.2 \times 10^{-7}$$

It can be seen that this is basically consistent with the extra solar redshift value $2 \times 10^{-7} < \Delta z < 10^{-6}$ at limb, which cannot be explained by other reasons.

4 Conclusions

From the gravitational redshift experiment done by Potzel in 1992, there is additional redshift data that is difficult to interpret by known theories. This paper assumes that these extra redshifts are caused by photon neutrino interactions. Based on this analysis, the data of the interaction between the solar neutrino and the gamma ray on the surface of the earth are obtained. This data shows that the intensity of photon neutrino interactions is still relatively large, and some of the existing high-sensitivity devices can effectively distinguish the effects of these interactions from other results. It also provides strong support for the test of photon neutrino interaction experiments specially designed in the future.

The results obtained from the Potzel experiment can also be used to explain the extra solar redshift at the limb. This extra redshift is difficult to explain with relativity and other known factors. Through comparison and calculation, it can be found that the mechanism of photon neutrino interaction is used to explain this extra redshift, and the theoretical calculation results can better match the experimental observation data.

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Appendix: Chinese Version

对光子中微子相互作用引起的光谱红移更精确的分析

程智
广州市白云区机场路百荣街 9 号

摘要：在过去有关引力红移的实验中，都有很多无法用已知理论进行解释的额外红移的存在。1990 年 Potzel 使用更高精度的穆斯堡尔效应验证引力红移，从中也发现了一些无法用现有理论进行解释的额外红移数据。本文假设这些额外的红移是由于光子中微子相互作用引起的，在此基础上，通过对 Potzel 实验结果做进一步的分析，得出了更准确的光子中微子相互作用引起的光谱红移数值。同时将分析结果用来解释太阳光面边沿 500nm 光谱的额外红移现象。这些额外红移数值也超出了相对理论引力红移的数值，且也无法用其他的原因来进行解释。本文分析结果表明，相较于其他的假设，光子中微子相互作用所引起的红移与实际观察的结果符合的非常好。

关键词：穆斯堡尔效应；光子；中微子；红移

More accurate analysis of redshift caused by photon neutrino interaction

Zhi Cheng
9 Bairong st. Baiyun District, Guangzhou, China. 510400. gzchengzhi@hotmail.com

Abstract: In experiments on gravitational redshift in the past, there were many additional redshifts that could not be explained by known theories. In 1990, Potzel used the higher-precision Mössbauer effect to verify the gravitational redshift, and found additional redshift data that could not be explained by existing theories. I assume that these extra redshifts are caused by photon neutrino interactions. On the basis of this, through the further analysis of the results of the Potzel experiment, a more accurate spectral redshift value caused by photon neutrino interaction is obtained. At the same time, the analysis results are used to explain the extra solar redshift of the 500 nm spectrum at the limb. These extra redshift values also exceed the value of the theoretical gravitational redshift and cannot be explained by other reasons. The results of this paper show that the redshift caused by the photon neutrino interaction is in good agreement with the actual observation compared to other hypotheses.

Key words: Mössbauer effect; photon; neutrino; red shift

1 引言

我在最近的研究中发现，光子和中微子之间可能存在相互作用【1~2】，这种相互作用超出弱相互作用的范畴。如果这样的光子中微子相互作用真实存在，将有助于我们使用更加轻便的设备来检测中微子，且结果更加直接。

文献【2】通过分析遥远星系光谱红移以及 Pound 在 1960 年进行的引力红移实验数据【3】，得出了一个光子中微子相互作用引起的红移数量级的估算。这样的分析问题主要在于数据精度不高。而在 Pound 的实验数据中也无法有效排除其他因素造成的系统误差。

本文尝试对更精确的实验数据进行分析。其中 Potzel 也是利用了穆斯堡尔效应来测量引力红移【4】，只是其精度更高，同时还使用了一个参考吸收体来进行对比，可以有效地减少系统误差的存在。

另外太阳光面边沿光谱红移【5~6】也是一个很重要的证据，因为其中存在引力红移以及其他已知因素无法解释的额外红移的存在。如果利用光子中微子相互作用能够成功解释这部分额外红移，将有助于确认光子中微子相互作用的强度，以及在地球上需要什么样精度实验装置的一起来进行测量。

2 Potzel 的实验数据分析

与 Pound 在 1960 年的实验不同，Potzel 使用的是能量更高的 ^{67}Zn，放射源发射的伽马射线能量可以达到 93.31kev，因此精度可以提高大约 6 倍。

Pound 的实验还有一个特点，就是使用了一个离放射源很近的参考吸收体作为频移的中心位置，这样可以比较好地减少实验中的系统误差。并且也发现了以现有的理论无法解释的系统误差的存在。

首先不考虑系统误差的存在。由于参考吸收体和实验吸收体离放射源的距离不同，参考吸收体非常靠近放射源，但还是有一个很小的距离。因此在实验装置从测试红移状态倒转过来测试蓝移的时候，参考吸收体的谱线还是会有很小的一个移动。在 Potzel 的实验中将这个装置变化所产生的误差忽略掉。不过在考虑除了引力所产生的红移或者蓝移现象外，其他的因素对谱线的影响，这时候可以考虑这部分谱线的频移。当然由于实验并非专门为测试这类频移而设计的，因此所得数据相对误差会比较大，但其数量级方面还是具有一定的参考价值的。

表 1 ^{67}Zn 穆斯堡尔效应测量数据（数据引自 Potzel 1992）【4】

频移类型	长度(mm)	等效重力加速度 g(m/s^2)	误差
R	1010	12.1	0.4
R	1010	11.9	0.4
R	1010	12.8	0.6
R	1010	12.6	0.6
R	1005	11.6	0.5
R	985	12.9	0.4
R	1039	11.5	0.3
R	1039	11.7	0.4
R	1039	11.4	0.8
B	1039	11.3	0.5

在表 1 中，频移类型 R 表示红移，B 表示蓝移。“长度”表示实验吸收体与参考吸收体之间的距离。这里将三个 0.58m 长度的数据删除，因为同蓝移长度差别较大，不适合进行比较。而等效重力加速度表示所测量出来的频移，相当于这个长度之类按照该加速度进行理论计算所引起的频移。

按照表 1 的数据可以计算出红移对应的等效重力加速度平均值为12.1 ± 0.5

而蓝移数据只有一个，对应的等效重力加速度为11.3 ± 0.5

这样可以计算出红移和蓝移之间存在一个等效加速度差值0.8 ± 0.5

理论计算是不应该出现这样的差值的，因此这个差值反映出的就是其他的非引力因素所导致出现的。符号为正，说明这个额外的频移属于红移效应。

按照标准的重力加速度 9.8 来计算，这样的额外红移效应大约为地球上每米高度引力红移数据的 4%

其次考虑 Potzel 数据本身无法解释的系统误差所引起的额外红移。Potzel 在文中仔细分析了各种可能引起这些额外红移数据的可能因素，认为做出了很多排除之后，数据仍然存在 6%的误差，且这个误差无法通过技术手段来进行消除。

这个系统误差而出现的红移与前面的 4%附加红移不同，这是实验设备中出现的绝对误差。而前面的 4%额外红移则是实验装置倒转之后数据的相对误差。两个数据都应该可以用来表示实验过程出现了无法解释的额外红移。因此这里取平均值大约 5%的额外红移数值。这意味着 Potzel 的实验中，其中至少有 5%的额外红移是无法用现有理论来进行解释的。我在这里假设存在中微子与光子的相互作用，这些额外红移大部分都应该是由于这种光子中微子相互作用所引起的。这样就可以估算出的光子中微子相互作用引起的红移大约为

$$\Delta z_b = \frac{\Delta f(b)}{f} \times 5\% = \frac{g}{c^2} \times 5\% = 5.5 \times 10^{-18}$$

考虑到 Potzel 实验的放射源能量是 Pound 实验放射源能量的 6.48 倍，精度会更高一些，因此这个数据要比文献【2】的估算准确一些。虽然频移很小，但在现有的穆斯堡尔实验精度之内还是能够测量出来。如果加大放射源与吸收体之间的距离、使用更高能量的放射源，在更高浓度的中微子环境中进行测量，结果可能会更加精确。

3 太阳光面边沿光谱额外红移

Pecker 在 1972 年提出光子与光子之间可能存在相互作用。如果存在这样的相互作用，则可以用来解释太阳光面边沿红移的结果。

太阳光面边沿红移是太阳光谱临边效应（Limb Effect）的一部分。太阳光谱的临边效应指的是太阳光谱从太阳光面中心到边沿光谱逐渐红移的现象。越是到太阳光面的边沿，则红移越大。而这无法用引力红移来进行完整的解释。

对于光面的内部，由于涉及到的因素比较复杂，包括引力红移，也包括电离气体、多普勒效应、转动效应等引起的频移。然而太阳光面的边沿则完全不受这些其他因素的影响，也就是说，如果存在已知的理论能够解释太阳光面边沿的红移效应，则这个理论就是引力红移。

不过 Pecker 指出[5]，实际情况就是太阳光面边沿的红移比根据广义相对论计算出来的引力红移要大，大约为 $2 \times 10^{-7} < \Delta z < 10^{-6}$，而通过相对论计算出来的引力红移大约为$z_g = 2.12 \times 10^{-6}$

Pecker 希望通过光子-光子相互作用的机制来解释这种额外红移现象。然而他们的计算结果表明光子-光子相互作用的效应在数量级上可能远小于引力红移的计算数据[5]。而 Cohen 在 1973 年也指出[6]，根据已有的一些实验数据来进行分析，这种光子-光子相互作用至少比引力红移小三个数量级。

因此基本可以排除光子-光子相互作用对太阳光面边沿光谱红移的影响。

这里考虑存在光子中微子相互作用，利用对 Potzel 实验结果，可以做如下分析：

首先简单估算一下。

按照 Potzel 的实验结果，额外的红移大约是引力红移的 5%，按此计算，太阳光面边沿引力红移数值的 5%大约为：$\Delta z = 1.6 \times 10^{-7}$，这与太阳光面边沿光谱的额外红移数量级基本一致。

其次本文也做一个具体的计算。

假设地球表面太阳中微子的浓度为 $n(b)/m^3$，太阳半径为 a，太阳到地球的距离为 b，假设中微子总量保持恒定，可以很方便地计算出太阳表面中微子浓度为：

$$n(a) = n(b)\left(\frac{b}{a}\right)^2$$

距离太阳为 r 的位置，其中微子浓度为：

$$n(r) = n\left(\frac{b}{r}\right)^2 \qquad （1）$$

设地球表面单位长度浓度为 n(b)的中微子与光子相互作用产生的频移为：

$$\Delta z_b = \frac{\Delta f(b)}{f} = \frac{kn(b)}{f} \qquad （2）$$

其中 k 为常数。

则距离为 r 处的中微子与光子相互作用单位长度产生的频移为

$$\Delta z_r = \frac{\Delta f(r)}{f} = \frac{kn(b)}{f}\left(\frac{b}{r}\right)^2 = \Delta z_b\left(\frac{b}{r}\right)^2$$

转换成积分形式可以获得光子从太阳光面边沿到达地球表面损失的总能量，即光谱的总红移频率：

$$\Delta z = \frac{\Delta f}{f} = \int_a^b \frac{kn(b)}{f}\left(\frac{b}{r}\right)^2 dr \qquad （3）$$

代入太阳半径以及太阳到地球的距离数值，并假设光子经过路径能够持续与所有中微子产生相互作用，再加上根据 Potzel 实验数据得出的红移上限，可以计算出总频移为：

$$\Delta z = \frac{\Delta f}{f} = \Delta z_b \int_a^b \left(\frac{b}{r}\right)^2 dr = 1.65 \times 10^{-4} \qquad （4）$$

可以注意该频移偏大，超过了引力红移引起红移两个数量级。而实际上光子的能量损失并没有这么多。说明可能存在下面 2 个原因：

1、由于本文通过分析 Potzel 实验数据得出的是一个红移上限，光子中微子相互作用引起的红移并没有 Potzel 实验中无法解释的红移数据那么大。尽管如此，计算结果也表明了光子中微子相互作用是足够引起额外红移的重要原因。

2、光子能够与太阳发射的中微子进行相互作用，但是相互作用的数量并没有那么多。存在一个实际的中微子数量与能够与光子产生相互作用的有效中微子数量这样的一个关系。

这里考虑有效中微子数量的问题。

由于中微子与太阳光子是同时发射的，因此在远离太阳的位置，中微子与光子飞行的夹角会变得非常小。

这里做一个假设，即每次光子只能够同一个中微子产生相互作用。

考虑到光子本身有波长，中微子只要在光子的这个波长范围以及光子飞行的方向之内，都会一直与该光子保持相互作用，因此如果中微子与光子的碰撞角度非常小，则在很长一段时间中，虽然光子运行的路径上遇到的中微子数量很多，但是很多其他的中微子并不会与该光子产生相互作用。

为了解决这一问题，这里引入一个碰撞长度的概念。即如果中微子运行在某个长度之内都有可能与光子产生碰撞，则这个长度就叫做中微子光子的碰撞长度。如图 1 所示。

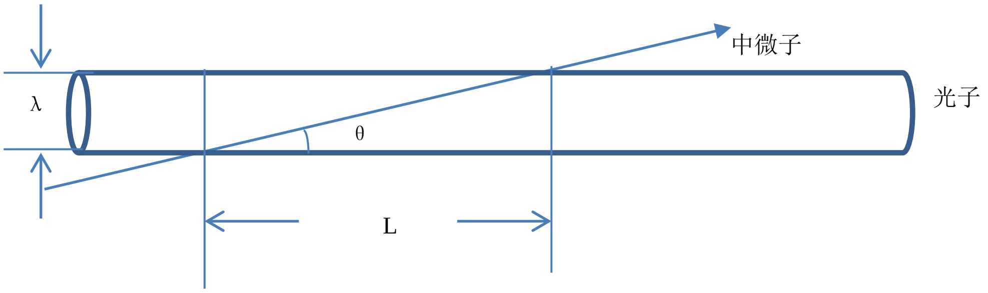

图 1 不考虑中微子波长的中微子光子碰撞长度（λ 表示光子的波长，L 为碰撞长度）

从图 1 中可以看出，碰撞长度 L 主要由光子与中微子飞行方向的夹角决定的。只要在碰撞长度 L 中，光子只能够与该中微子产生相互作用。但是位于碰撞长度之内的其他中微子仍然会被计入光子所经过该长度的中微子密度。

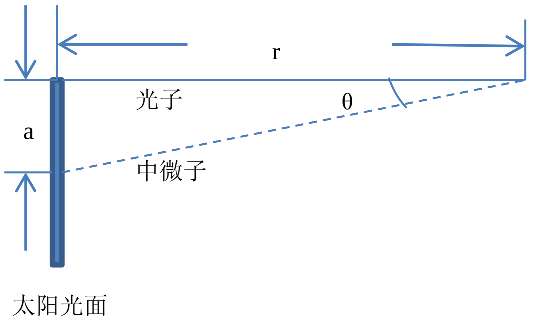

图 2 光子中微子相互作用与太阳光面之间距离的关系

图 2 显示的是光子中微子碰撞点与太阳光面之间的距离。这里为了简化分析过程，将太阳光面看作一个平面。其中 a 为太阳光面的半径，中微子可以从太阳光面的任意一个位置发出，计算的时候取光面中心位置作为一个中微子发射位置的平均值。而 r 为碰撞点距离太阳光面上边沿的距离。结合图 1 和图 2，可以得出下面的公式：

$$\frac{\lambda}{L} = \frac{a}{r}$$

即：

$$L = \frac{\lambda r}{a}$$

碰撞长度的存在意味着中微子“变大”了，变大了多少倍也就意味着该处能够与光子产生相互作用的有效中微子的密度减少了多少倍。

这里假设中微子本身的波长为λ_v，地球表面位置的中微子密度为 n(b)，现在相互作用长度增加到了$\lambda_v + L$，则因为碰撞长度的增加，有效中微子密度为：

$$n'(b) = \frac{\lambda_v}{\lambda_v + L_b} n(b)$$

同样，距离地球 r 处的位置，有效中微子数量与实际中微子数量之间的关系为：

$$n'(r) = \frac{\lambda_v}{\lambda_v + L_r} n(r)$$

则：

$$n'(r) = \frac{\lambda_v}{\lambda_v + L_r} n(b) \frac{b^2}{r^2}$$

注意到 Potzel 等人的实验使用的是伽马射线而不是与中微子一同发射的太阳光线，它是直接与光子相互作用的，因此 Potzel 实验中的有效中微子密度就是 n(b)。即：$\Delta z_b = \frac{\Delta \mathrm{f(b)}}{f} = \frac{\mathrm{kn(b)}}{f}$

然后考虑一个近似条件：L ≫ λ_v，代入公式（4），可以得到：

$$\Delta \mathrm{z}_0 = \int_a^b \mathrm{kn'(r)dr} = \Delta \mathrm{z}_b \int_a^b \left(\frac{b}{r}\right)^2 \frac{\lambda_v a}{\lambda r} dr = 8.3 \times 10^{-5} \frac{\lambda_v}{\lambda}$$

这主要考虑到 L 与λ_v数量级差不多的位置，基本上就是位于太阳的表面。在不考虑碰撞长度的情况下，仅仅太阳表面光谱红移数量级是非常小的，大约为 10^{-12}，可以忽略。

由于β衰变的平均能量大约 300kev，这可以看作是太阳表面释放出来的中微子的平均能量，相当于波长 4.1nm，而所分析的太阳光谱的波长为 500nm。

因此：

$$\Delta \mathrm{z}_0 = 8.3 \times 10^{-5} \frac{\lambda_v}{\lambda} = 8.2 \times 10^{-7}$$

可以看出这与太阳光面边沿无法解释的额外红移值$2 \times 10^{-7} < \Delta z < 10^{-6}$基本一致。

4 结论

从 1992 年 Potzel 所做的引力红移实验来看，存在通过已知的理论难以解释的额外红移数据。本文假设这些额外的红移是由于光子中微子相互作用而引起的。在此基础上深入分析获得了太阳中微子与伽马射线在地球表面相互作用的数据。该数据显示光子中微子相互作用的强度还是比较大的，通过现有的一些高灵敏度设备能够有效地将这些相互作用所产生的效果与其他的结果区分开来。并为今后专门设计的测试光子与中微子相互作用实验提供强有力的支持。

从 Potzel 实验中获得的结果也可以用来解释太阳光面边沿光谱额外红移的问题。这种额外的红移是用相对论以及其他的已知因素难以解释的。通过对比和计算，可以发现用光子中微子相互作用的机制来解释这一额外红移，理论计算结果能够比较好地符合实验观察数据。

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