Some Problems About CP Violation In The Neutral Kaon Decay

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Abstract – The CP violation concluded from the neutral Kaon decays in 1964 causes our curiosity about whether it is true. The experimentally observed particles are K_1 and K_2 which experiences 2π decay in the former and 3π in the latter. In our new explanation, the long-lived K_L is more like the superposition of both K_1 and K_2 states because the 2π decay events are indeed originated from K_1 and CP violation doesn't take place on K_2. Om the other hand, as long as the K_1's energy is large enough, it can move a very long distance before decay. This situation is like muon passing through a much longer distance to decay. Besides, the estimations of K_1's and K_2's lifetimes have to include the data in 1964 which may result in significant corrections.

Keywords: Koan, meson, CP violation, muon,

The K mesons have been found in 1947 and there are four K mesons, the K^0, $\bar{K}^0$, K^-, and K^+[1]. In 1964, it was been found that the neutral kaon decay experienced a little deviation which is so-called CP violation [1-3]. $\bar{K}^0$ is the K^0's anti-particle and both of them can turn into each other through the second-order weak interaction [1,3], in which the process is

$$K^0 \leftrightarrow \bar{K}^0. \quad (1)$$

Originally thinking, the Kaon decay obeys CP symmetry. The eigenstates of CP are K_1 and K_2 states, which are the combinations of K^0 and $\bar{K}^0$ states [1], are expressed as

$$|K_1\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle - |\bar{K}^0\rangle), \quad (2)$$

and

$$|K_2\rangle = \frac{1}{\sqrt{2}}(|K^0\rangle + |\bar{K}^0\rangle). \quad (3)$$

K_1 and K_2 states have different decay processes, and the former decays to 2π and the latter to 3π because of CP-conservation [1,3]:

$$K_1 \rightarrow 2\pi. \quad (4)$$

and

$$K_2 \rightarrow 3\pi. \quad (5)$$

The exchange decay processes between K_1 and K_2 are forbidden [3]. According to the previous data [3], scientists thought K_2's average lifetime much longer than K_1 so it shouldn't observer the 2π decay after a longer distance as shown in Fig. 1 [2]. However, this finding is based on the average lifetimes for both K_1 and K_2 which respectively are [3]

$$\tau_1 = (8.954 \pm 0.004) \times 10^{-11}\, sec. \quad (6)$$

and

$$\tau_2 = (5.116 \pm 0.021) \times 10^{-8}\, sec. \tag{7}$$

The CP violation in the Kaon decay was concluded in 1964 and the long-lived non-perfect eigenstate of *CP* was proposed as

$$|K_L\rangle = \frac{1}{\sqrt{1+|\epsilon|^2}}(|K_2\rangle + \epsilon|K_1\rangle), \tag{8}$$

where ϵ is the K_1's probability amplitude and $|\epsilon|^2$ is proportional to the ratio of K_1 detected by the detector. However, such expression means the occupation of K_1 is [3]

$$|\langle K_1|K_L\rangle|^2 = \frac{|\epsilon|^2}{1+|\epsilon|^2}. \tag{9}$$

It also means that after a long distance, the occupation of K_1 is still non-zero. The 2π decay process is thought coming from K_1 [4] and the so-called CP violation doesn't take place on K_2. The experimentally observed particles are actually K_1 and K_2, not the K_L. The reason is that the records in experiments are directly related to the charged pions [1-3], which originate from the K_1 or K_2 decays. In quantum theory, K_L in Eq. (8) is more like the superposition of two states, K_1 and K_2 states. Although it was claimed the non-perfect eigenstate of *CP* more than 50 years, we are still curiosity about the results of the experiments. In Fig. 1, when the moving distance of Kaons is short or considering the initial time less than 10^{-10} *sec.* after Kaons' birth, the number of K_1 and K_2 should be equal to or close to each other. As time goes by, K_1 experiences quickly decays to 2π and many K_2 still exist until 10^{-8} *sec.* If we use a state $K_L(z)$ to represent the mixing of both K_1 and K_2, then it is expressed as

$$|K_L\rangle = \frac{1}{\sqrt{1+|\epsilon(z)|^2}}(|K_2\rangle + \epsilon(z)|K_1\rangle), \tag{10}$$

where *z* is the distance in the Kaon's moving direction. ϵ can be also the function of time *t*. The ratio of K_1 in this case and in the experiments is

$$|\langle K_1(z)|K_L(z)\rangle|^2 = \frac{|\epsilon(z)|^2}{1+|\epsilon(z)|^2}. \tag{11}$$

It is obviously that this ratio is a function of the moving distance *z* and it is not a constant because of the K_1 decay. K_1 decays gradually and rapidly in the real experiments so $|\epsilon|^2$ decreases as *z* or *t* increases. This explicitly tells us that K_1 still possibly survives even the moving distance is very long and the revolution time even reaches 10^{-8} *sec.* after their birth. It also tells us that K_1's lifetime can overlap K_2's as shown in Fig. 2, and the estimation of the K_1's average lifetime needs to include the data in 1964 [2] which may correct the K_1's average lifetime in Eq. (6) meaningfully. The experimental setup was fixed at 57 feet from the end of the collimator to the detectors in 1964 [2], and the data for 2π decay were recorded 45 out of 22700 events. If we increase or decrease the detecting length in the experimental setup, the recording data will be predicted to change. So the conclusion of *CP* violation from the experimental results in 1964 [2] seems to have some fundamental problem: is it real the verification of *CP* violation? What if the 45 out of 22700 events in 1964 were calculated in the K_1's average lifetime? If the CP violation doesn't take place on K_2 and K_L is only a superposition state of K_1

and K_2, can we still conclude the happening of CP violation in these experiments?

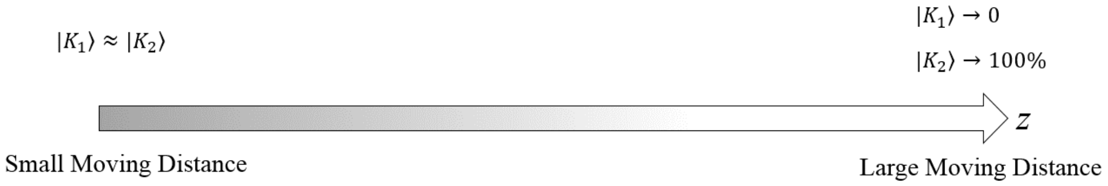

Figure 1. K_1 and K_2 decay as the moving distance increase and K_1 decreases much faster than K_2 due to much shorter lifetime so theoretically speaking, K_1 will disappear and only K_2 will survive as long as the moving distance is long enough.

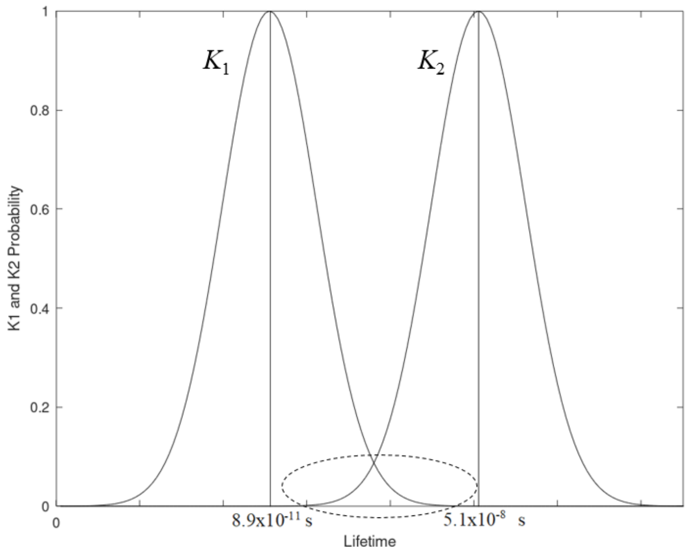

Figure 2. The demonstration of the overlap between K_1 and K_2 in the lifetime statistics. The dashed-line ellipse means that very few K_1 can survive as long as the K_2's lifetime so K_1 possibly appears after 10^{-8} *sec*. It is the possibility that the experiments recorded 45 events about 2π decay in the total amount of 22700 in 1964 [1-2].

Except for the truth of no CP violation on K_1 and K_2, furthermore, this conclusion might ignore two things. One is the identification of the K_1's average lifetime as mentioned previously. It is obviously if the information about the average lifetime is incorrect, then this conclusion would be problematic. As we know, the lifetime of K^- and K^+ is almost equal and so dose their mass. It is recorded that this mass difference is about (0.032±0.009) MeV/c^2 between them [3]. This difference is within the statistical error and is even much larger than the difference between K_1 and K_2, which is only $3.5\text{x}10^{-12}$ MeV/c^2 [1,3], less than 10^{-14} K_1's or K_2's mass. This very tiny mass difference is also within the statistical error. Both mass is much more identical than the K^+ and K^- pair. Therefore, when we find the 2π decay events in the long-lived K_L state, it makes the K_1's statistical distribution in time lack of these data in 1964. If the CP violation were true, then it will happen no matter how long the moving distance it is. It is suggested that the experiments would be better done after a very long distance to make sure the fraction of K_1 become to a convinced zero value.

The second thing is that we have to calculate whether K_1 can move a longer distance and survive with most K_2 as long as the K_1's energy large enough? The average lifetime is defined in the rest frame, and most of kaons move close to the light speed c so their moving distance could be much longer than the distance equal to c times lifetime τ. For example, the muon detection is a good demonstration. As we know, in nature muons are originally from the high-energy cosmic ray. The decay of proton takes place to produce muons due to the collision with molecules in the air. Considering the muon decay producing by the cosmic ray. The lifetime of muon is very short that it seems to detect muon much few on the ground. However, the lifetime is recorded in the rest frame, so in reality more high-speed muons can reach ground after they are produced at a very high place above the sea level. The muon's average lifetime is 2.197x10^{-6} *sec.* in the rest frame [1,2-4] and the relativistic effect makes them be able to move more than 15 km and be detectable on the Earth, not only 660 *m*. In this muon decay case, the Lorentz factor,

$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}, \tag{12}$$

is as large as 23 because of its velocity v very close to c. If some K_1 and K_2 particles have enough high energy, they can also move through a much long distance like muon. In 1964's experiments, the Kaon decays after the collimator took place and pions move d57 feet captured by the detectors. This collimator is about or less than 1.5 *m* in length. We are curiosity about whether the data for calculating the average lifetime is recorded after a very long moving distance like muon moves about 15 km long to reach the Earth?

Since the neutral K_0 and its anti-particle belong to a strong eigenstate with no definite lifetime [1,3], the two eigenstates of *CP* should have a relatively large lifetime deviation in statistics. The report in 1964 showed that the K_1's mean momentum p is 1100 MeV/c [2]. By the relativistic principle,

$$E = \gamma m_0 c^2 = [(m_0 c^2)^2 + c^2 p^2]^{1/2}, \tag{13}$$

its velocity equals to 0.91099 c where m_0 is the K_1's or K_2's rest mass, 498 MeV/c^2 [1,3,4]. It means that the K_1 can move a longer distance to decay to 2π so it happens in the long-lived K_L state as shown in Eqs. (8) and (9). If the incident proton transfers almost all its energy to Kaon, γ is as large as 70 so it can move about 1.8 *m* longer than the length of the collimator in 1964. Its occupation is a function of z or t as shown in Eq. (10) and (11) and gradually and rapidly decays in z or t. This fact possibly results in the findings of the 2π decay events at large z or t condition.

In conclusion, we re-explain the role of the long-lived K_L state and think it more like the superposition of both K_1 and K_2 states. In this framework of new explanation, the 2π decay events are related to the K_1's occupation in this mixing state. It is based on the truth that the 2π decays originate from K_1 and no CP violation takes place on K_2. In particle physics, K_1 is responsible for the 2π decay events and K_2 for the 3π decay events. It makes us ask whether the CP violation in the neutral Kaon's decays is real? In fact, the occupation of K_1 depends on the moving distance z and evolution time t. Furthermore, the calculations of the average lifetimes have to include the data in 1964 which may be not counted and considered in the statistics. The superposition where the concept of the quantum theory is applied can reasonably explain the experimental results, and the K_1's and K_2's average lifetimes can have meaningful corrections.

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