Some Problems about CP Violation in the Neutral Kaon Decay

Ting-Hang Pei
Thpei142857@gmail.com

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. The observation of 2π decay event in K_L indicates that it contains K_1 component. On 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 take place decay. Besides, the estimations of K_1's and K_2's lifetimes have to include the data in 1964 which may lead to significant corrections.

Keywords: Koan, meson, CP violation, muon, pion

The K meson was discovered in 1947 and a total of four K mesons were found, namely K^0, $\bar{K}^0$, K^-, and K^+[1]. In 1964, it was further 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

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

It was originally thought that 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], 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 of K_1 and K_2 decay processes in Eqs. (4) and (5) is 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 long distance as shown in Fig. 1 [2]. However, this assumption is based on the average lifetimes for both K_1 and K_2 which respectively are [3]

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

and

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

In 1964, the CP violation in the Kaon decay was summarized and the long-lived non-perfect eigenstate of *CP* was proposed as [1,3]

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

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 [3] 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. The 2π-decay events must come from K_1, and the 3π-decay events must come from K_2. In quantum theory, K_L in Eq. (8) is more like the superposition of two states, K_1 and K_2 states. Then this expression in Eq. (8) obviously links the true that the 2π decay events are original from K_1 and K_2 is responsible for the 3π decay events. 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 Kaon's moving distances is short or considering the initial time less than 10^{-10} *sec*. after neutral Kaons' birth, the number of K_1 and K_2 should be equal or close to each other. As time goes by, K_1 experiences decays quickly to 2π and many K_2 still exist until 10^{-8} *sec*. If we use a state $K_L(z)$ to represent the mixture of K_1 and K_2, then

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

where z is the distance in the neutral 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

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

It is obviously that this ratio is a function of the moving distance z and it is not a constant because of the rapid 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 exists even if the moving distance is very long and the revolution time even reaches 10^{-8} *sec*. after they were born. It also reveals 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 can correct the K_1's average lifetime in Eq. (6) meaningfully. In 1964, the experimental setup was fixed at 57 feet from the end of the collimator to the detectors

[2], and the 2π-decay data were recorded in 45 of 22700 events. If we increase or decrease the collimator or the detecting length in the experimental setup, the recorded data will be changed. Therefore, the conclusion of *CP* violation from the experimental results in 1964 [2] seems to have some fundamental questions: is it real the verification of *CP* violation? What if the 45 of 22700 events in 1964 were included in the statistics of K_1's average lifetime? If the CP violation doesn't occur on K_2 and K_L is only a superposition state of K_1 and K_2, can we still conclude the CP violation occurred in these experiments?

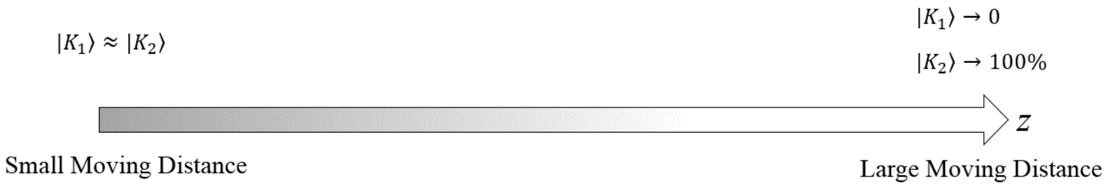

Figure 1. K_1 and K_2 decay as the moving distance increase and K_1 decreases much faster than K_2 due to the much shorter lifetime so theoretically speaking, K_1 will disappear and only K_2 will survive as long as the moving distance is long enough.

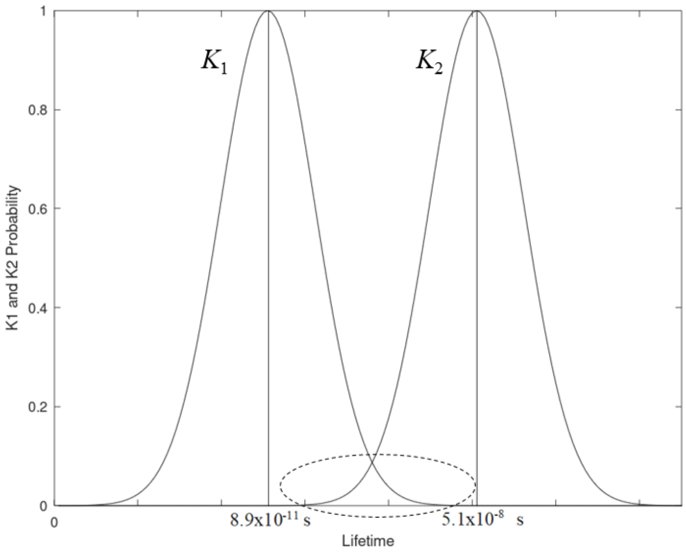

Figure 2. The demonstration of the overlap between K_1 and K_2 in the lifetime statistics. The dashed-line ellipse means that very few K_1 can survive close to the K_2's lifetime so K_1 possibly appears after 10^{-8} *sec*. It is one of the several possibilities that the experiments recorded 45 events about 2π decay in the total amount of 22700 in 1964 [1-3].

Except for the truth of no CP violation on K_1 and K_2, furthermore, the conclusion of CP violation 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, as is 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 thought to be induced by the weak interaction. Both masses are much closer 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 1964 lack such data in time. When we add the data in 1964, then the average lifetime in Eq. (6) may be meaningfully different.

The second thing is that we have to calculate whether K_1 can move longer than the predicted distance and survive with most K_2 as long as the K_1 has enough energy? The average lifetime is defined in the rest coordinate frame, and most of Kaons are close to the speed of light c so they can travel much longer than the distance equal to c times lifetime τ. For example, the muon detection is a good demonstration. It is well known that most of muons in nature originally come from the high-energy cosmic ray. Due to collisions with molecules in the air, protons decay to produce muons. Consider the muon decay originally produced by cosmic rays. The lifetime of muon is very short that it shall detect much few muons on the ground by prediction. However, the lifetime is the value in the rest coordinate frame, and therefore, in reality, more high-speed muons can reach ground after they are generated at very high places above the sea level. The muon's average lifetime is 2.197×10^{-6} *sec.* in the rest coordinate frame [1-4] and the relativistic effect makes them be able to move more than 15 km, not only 660 *m*, and be more detectable on the Earth. 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 energy high enough, they can also travel through a much long distance like muon. In 1964's experiments, the neutral Kaon decays after the collimator took place and pions moved 57 feet captured by the detectors. This collimator was about 1.2 *m* in length. We are curiosity about whether the data of K_1 moving a very long distance is also included in its average lifetime as muon moves about 15 km long to reach the Earth?

Since the neutral Kaon 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 was 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 exhibits another possibility that the K_1 can move a very long 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 can be as large as 60 so its movement is about 1.60 *m* longer than the length of the collimator in 1964. Its occupancy is a function of z or t as shown in Eq. (10) and (11) and gradually and rapidly decays in z or t. Actually, the collimator is about 1.2 *m* in length, and it only needs 3/4 total energy of the incident proton, about 22.5 GeV in which γ is 45, to be able to pass through the collimator. This fact also possibly results in the discoveries 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 the 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 so K_L is much more like a superposition state. 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 by adding the data in 1964.

Acknowledgement

This research is under no funding.

Reference:

1. David Griffiths, *Introduction To Elementary Particles* (John Wiley & Sons, Inc., 1987).
2. J. H. Cristenson, J. W. Cornin, V. L. Fitch, and R. Turlay. "Evidence For The 2π Decay of The K_2^0 Meson," *Phys. Rev. Lett.* **13**, 138 (1964).
3. B. R. Martin and G. Shaw, *Particle Physics* (John Wiley & Sons, Inc., 2nd ed., 1992).
4. C. Amsler et al., "Review of Particle Physics," *Phys. Lett. B* **667**, 1 (2008). http://peg.lbl.gov/2008/listings/s013.pdf.