Strangeness

So, charge conjugation reverses the sign of charge. Thus, some neutral particles such as π^0 and photon have themselves as their anti-particle; nothing changes under charge conjugation. However, other neutral particles such as neutron and K^0 do not have themselves as their anti-particles. Anti-neutron and $\bar{K}^0$ are their anti-particles. It's because the electric charge is not the only type of charge a particle can have, even though we normally refer to the electric charge when we say simply "the charge." Neutron has 1 for what is called "baryon number," and thus, anti-neutron has -1 for baryon number. As their baryon numbers differ, neutron and anti-neutron are distinct. K^0 has 1 for what is called "strangeness," and thus, $\bar{K}^0$ has -1 for strangeness. As strangeness differs, K^0 and $\bar{K}^0$ are distinct. In this section, we will deal with the history of the discovery of strangeness, because it's an interesting one. We will closely follow a popular physics book *Quarks: Frontiers in Elementary Particle Physics* by Yoichiro Nambu, the Japanese American Nobel laureate in physics.

In December 1947, the same year charged pions were discovered, a yet new particle was discovered. See Figure 1.(I will add the figure as soon as I get a copyright permission.) Cosmic rays stroke a lead plate, producing a new particle (now called K^0) which then decayed into a pair of charged pions. This new particle, first called V^0, is an example of V particles; as the trajectory of their decay product looked like the upside-down 'V,' they were called V particles. There seemed to be many different types of V particles. For example, some charged V particle, $V^{\pm}$ decayed into three charged particles, while other $V^{\pm}$ decayed into another charged particle and V^0. Strangely, it often happened that two V particles were photographed in the same picture. This was puzzling because the probability that one can see a V particle in a picture was very low, which would imply that the probability that one can see two V particles in a picture would be virtually zero, if the appearances of each V particle were independent events.

Therefore, it is plausible that the two V particles were created simultaneously. Actually, the two V particles need to be created always simultaneously. Otherwise, we will predominantly see single V particle in a picture. We can guess that the reason why we didn't see two V particles, but only one in some pictures is that the other V particle passed by the cloud chamber without decaying or that the range of picture taken was not wide enough.

So, why are two V particles created always simultaneously? We can guess that it is because there is a conserved quantity. For example, an electron (e^-) and a positron (e^+) are created simultaneously because of charge conservation, but the simultaneous creation of e^- and e^- or e^+ and e^+ is impossible. Thus, Gell-Mann proposed a new conserved quantity called "strangeness" (S); when cosmic rays strike matter a pair of V particles with positive strangeness and negative strangeness are created.

Then, what happens to V particle once created? If strangeness were conserved, the decay products of V particle should inherit its strangeness. However, we have seen that a V particle decays into a pair of charged pions, which have no strangeness! So, one may guess that there is a third decay product that carries strangeness which did not show up in the picture. However, a detailed analysis of energy-momentum conservation of the decay process showed that there was no such invisible decay product that would have carried strangeness.

So, we are stuck at a dead end. There is only one way to save the situation: relaxing the conservation law of strangeness, i.e. that strangeness is not always conserved, but there are exceptions. Nambu says in his book that researchers should always try every possibility even though relaxing a physics law like this may not seem to be the correct attitude for physicists who should always respect strict rules. Moreover, this relaxation gives great benefits.

First of all, as the decays of V particles are "almost" forbidden, their life times must be relatively long compared to the natural life time scale expected from the uncertainty principle. We have $\Delta E \times \Delta t \geq \hbar$, and if we plug in the mass of V particle into ΔE, we expect Δt to be around 10^{-23} seconds, which barely translates into the trajectory 10^{-13} cm, even though the speed of V particle may be comparable to the speed of light! However, in reality, after being created at metal plates, V particles often travel few centimeters before decaying. It means that the life times of V particles are at least order of 10^{-10} seconds, which are more comparable to the life time of pions (10^{-8} seconds) or muons (10^{-10} seconds) that decay through weak interaction than to the natural life time scale just mentioned. This suggests that the decay of V particle is through weak interaction. This later turned out correct. So, the strangeness isn't conserved by weak interaction.

Final comment, we now know that a particle with strangeness 1 has an anti-strange quark in it, a particle with strangeness -1 has a strange quark in it, a particle with strangeness -2 has two strange quarks in it and so on. Strong interaction, electromagnetic force and gravity cannot change the flavor of quark, (i.e. type of quark, such as up, down, strange) but weak interaction can.

Summary

- Some (electrically) neutral particles have themselves as their own anti-particles, as charge conjugation reverses the sign of charge.
- Other (electrically) neutral particles do not have themselves as their own anti-particles, as there are other kinds of charge than electric charge, and these electrically neutral particles are not neutral under these charges.
- Weak interaction doesn't conserve strangeness.
- Strange particles, which have non-zero strangeness are *not* created through weak interactions, so it is always created in pairs, one with strangeness 1 and the other with strangeness -1.

- However, strange particles decay through weak interactions, which change strangeness.
- A particle with strangeness 1 has an anti-strange quark. A particle with strangeness -1 has a strange quark.
- Weak interaction can change the flavor of quark, so it can change strangeness.
- Other forces do not change the flavor of quark.