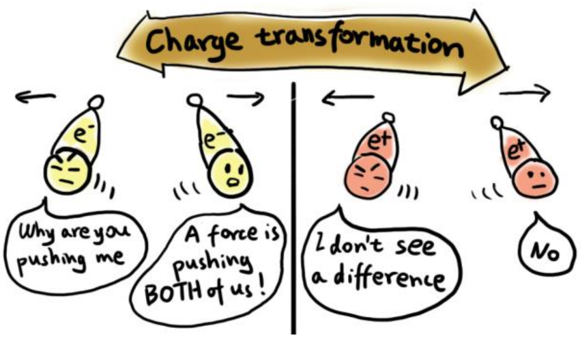
Discrete Symmetries

In physics, “symmetry” can refer to that some properties remain unchanged after applying some types of transformation. There are continuous symmetries and discrete symmetries. Here we are going to talk about three types of discrete symmetries: C (charge), P (parity) and T (time).

C symmetry

Charge symmetry. A simple explanation of charge conjugation transformation is that it turns a particle into its antiparticle. For example, an electron has charge -1, its antiparticle: positron, has charge +1.

Particles with same type of charges repel each other. For example, two electrons. After a charge transformation, both electrons turn into positron. And they’ll still repel each other, as they still have same type of charge.

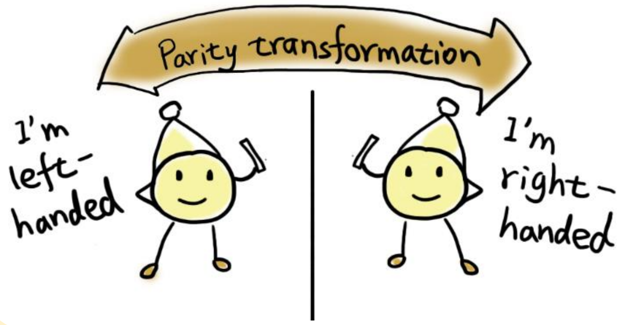


This repelling force is an electromagnetic force. This interaction does not change after applying charge transformation, which means charge symmetry is obeyed (or say, conserved) in electromagnetic interactions.

P symmetry

Another symmetry is the **parity** symmetry. Parity transformation is a spacial inverse: imagine being in a mirrored world! If a particle is lefthanded, P transformation turns it into being righthanded.

The electromagnetic force is, again, same for lefthanded particles and righthanded particles. So, parity is also conserved in electromagnetic interaction.



T symmetry

There is also **time** symmetry. Time reversal transformation inverses time. Let’s use an imaginary example: imagine you went to Hogwarts and learned to turn yourself into a dog and to turn back. Your friends happily took a video of this transformation. If you play the video backwards, it shows you the process with inversed time.

If your magic education trained you to turn into a dog with the same amount of time turning back into human, you wouldn’t be able to tell the difference whether you are playing the video backwards: a video appearing to be a dog turning into you could be a video of you turning into a dog played backwards! This means T symmetry is conserved in the “dog interaction” responsible for this transfiguration process.

In the particle case, it would be turning into its antiparticle, decaying into other particles, or both.

CP Violation

We were only talking about the cases where symmetries are conserved, now we’re going to talk about when they are not, which we call “violated”.

There are four types of fundamental forces: electromagnetic, strong, weak and gravitational. C, P and T symmetries are all violated in weak interactions.

CPT is the product of charge conjugation, parity and time reversal transformations. By now, scientists believe that CPT is conserved in all these interactions, but CP violation was already found in weak interactions. CP violation can also be called T violation, as if CPT is conserved and CP is violated, T must be violated.

Imagine if you found out that turning into a cat takes longer than turning back into human, then CP is violated in “cat interaction”, as then you can tell when time is going backwards.

Triple Product Asymmetry

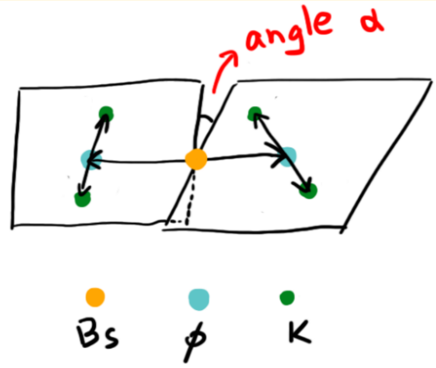
Turning into a cat is just an example. Trying to find CP violation in experiments is much more complicated. One of the ways is to measure the triple product asymmetry in particle decays.

This way does not work for every decay mode. But the $B_s \to \phi\phi$ decay is one of the special ones. In this decay, if the triple product is asymmetric, it means there is CP violation and physics that we don't know. So, what is triple product?

Triple Product

Take two sticks and place them like an "X" shape, you'll find that this defines a plane. After the B_s meson (particles consist of two quarks are called mesons) decays into two ϕ mesons, each ϕ then decays into two K mesons (K^+ and K^-). The directions that the ϕ and K travels define a plane. One B_s decays to two ϕ, each of them decays and defines a plane – so we get two in total.

The word "triple product" can mean many things in science. Here it is defined as a number calculated from the angle α between the two planes (as shown in picture). Let's call it U.



How do we get this decay and measure the angle to calculate U? Experiments! In the large hadron collider at CERN, the B_s mesons are produced in proton-proton collisions, and then decay in the detector, which then measures various properties of the final particles, and tell us what U is for this decay "event".

The LHCb detector at CERN.
Image: Maximilien Brice/CERN

But there are so many things going on in the detector! Two beams of protons collide together – this means lots of collisions in a short time. The collisions also produce various particles other than the B_s meson. The detector does identify the decay we want, but there are background noises, i.e. some data that's not really from this decay tricking the detector and sneaking into our dataset.

Therefore, after collecting hundreds or thousands of decay events, we need to analyse the data, in order to get the number of events that have positive U and negative U respectively. Then the asymmetry can be calculated. If we use N to denote the number of events, the asymmetry $A = \frac{N(U>0) - N(U<0)}{N(U>0)+N(U<0)}$.

In my project my job was to analyse data from the detector and calculate A. The result obtained is consistent with CP conservation. But in the future, we can try to get a more precise result and see if there is a discrepancy with the theory. It's also possible that we will find the asymmetry in other decay modes.