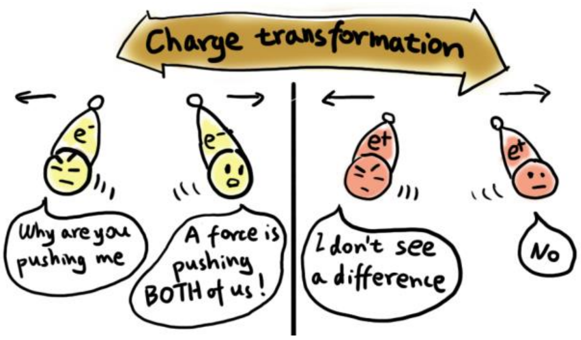
Discrete Symmetries

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 transformation is that it turns a particle into its antiparticle. For example, an electron has charge -1, its antiparticle: positron, has charge +1.

Two electrons repel each other because they both have negative charge. After a charge transformation, both electrons turn into positron. And they'll still repel each other, as they still have the same type of charge.

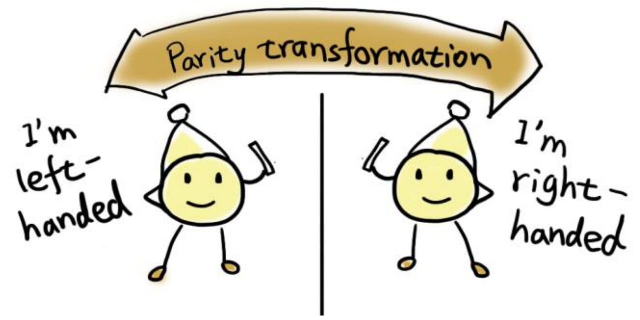


This repelling force is an electromagnetic force. This interaction does not change after applying charge transformation. This is because charge symmetry is obeyed (or say, conserved) in electromagnetic

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. Let's use an imaginary example. Imagine if you went to Hogwarts and learned to transform yourself into a dog and to transform back. Your friends happily took a video of your transformation.

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 "dog transformation".

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

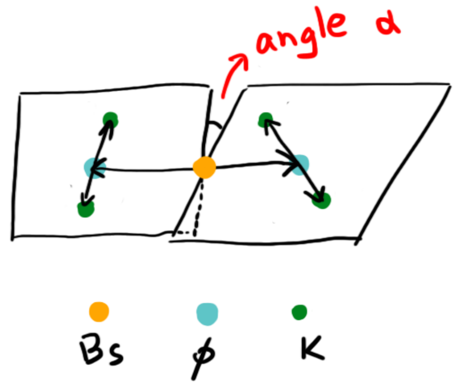
CP Violation

CP is doing a charge transformation together with a parity transformation. Previously we were only talking about the conservation of symmetries. Actually, it's not always the case.

There are four types of fundamental forces: electromagnetic, strong, weak and gravitational. A lot of symmetries are not conserved (then we call it "violated") in weak interaction.

By now, scientist believe that CPT is still conserved in all these interactions, but CP violation was already found in weak interaction. 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 transformation", as then you can tell when time is going backwards.



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, they then decay in the detector, which measure 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

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. So, what is triple product?

Triple Product

Take two pens or chopsticks and put them into an "X" shape. You'll find that this defines a plane. B_s consists of two quarks, so it belongs to a type of particle called meson. After the B_s meson 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 – 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.

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 $A = \frac{N(U>0) - N(U<0)}{N(U>0)+N(U<0)}$

By now the result did not show an asymmetry in this decay. But in the future we can try to get a result with better precision and see if there is a discrepancy with the theory. It's also possible that we will find the asymmetry in other decay modes.