Asymmetry from which we are born

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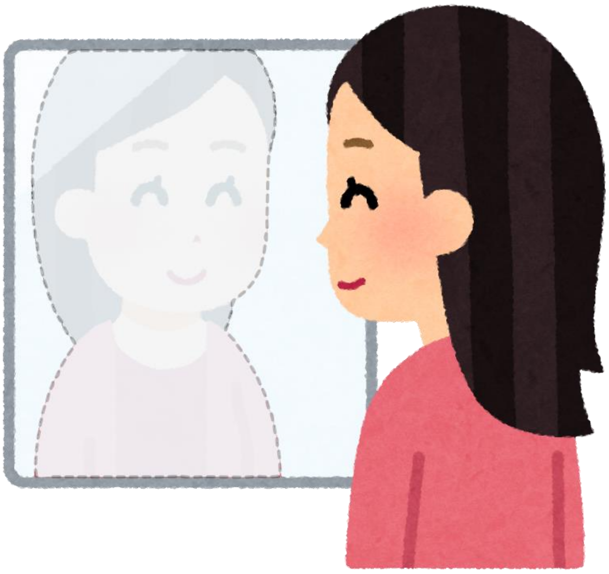

Imagine observing a game of billiards in a mirror. The balls should behave in the same way as in a usual game. This is because the physical law in the mirror world governing movements of the balls is the same as ours, namely Newtonian mechanics. In other words, Newtonian mechanics has a symmetry about mirror reflection.

More generally, a symmetry is said to exist when some property is preserved under some operation. In the example above, our world preserves the law of mechanics under mirror reflection. The operation associated with a symmetry is often called a symmetry operation.

One important symmetry arises from the concept of antiparticles. For every particle species, there is an associated particle species called antiparticle. They have the same mass but opposite charges as the corresponding particles. For example, positrons, the antiparticle of electrons, have the same mass as that of an electron but the same electric charge as a proton, not an electron. You can think of an antiparticle as the twin of the particle.

What happens if you swap all particles and their antiparticles? This operation is called charge conjugation. If you can describe the new world with the same law of physics as the original world, nature is said to have the charge conjugation symmetry. The charge conjugation symmetry is often called C in short.

Two other symmetry operations are as important as charge conjugation: parity and time reversal. Parity is the mirror reflection I mentioned at the beginning, and often denoted as P. Time reversal is what you see when you play a video backward, and denoted as T. The operations C, P and T are the most basic symmetry operations in physics.

The three operations are indeed symmetries of the most physics relevant to our daily lives. It is natural to assume that all the three and any combinations of them (e.g. doing C and P at the same time is called CP) are symmetries of the world, as in the example of billiard. Physicists also initially thought that way.

However, it was not the case. After the discovery of C- and P-violation, CP violation in the decay of a particle called kaon was discovered [1]. Roughly speaking, a neutral kaon was caught transforming into its antiparticle. This process changes the way the state transforms under CP, so CP is violated. Since the first discovery, the existence and the nature of CP violation have been probed in many ways.

To date, any combinations of C, P and T except CPT (the operation to do all the three at once) are known to be violated. Especially, the violation of C and CP has far-reaching consequences.

Symmetries are important in that they dictate what can happen and what cannot. For instance, imagine a swinging pendulum with a ball-shaped blob. Clearly, the time it takes to go from left to right and that of the opposite way are the same. You can see this from the pendulum's symmetry about the vertical line at the center. The symmetry must be broken to create a difference between the two intervals.

An analogous situation could have happened in the early Universe. Suppose the Universe started with no matter. Energy in other forms was converted into matter, but also to antimatter, matter made only of antiparticles. If matter and antimatter were completely symmetric, they would have had the same amount. In such a case, they are known to eventually annihilate with each other. Therefore, it ends up with an empty, boring Universe[1].

In reality, the Universe contains almost only matter and no antimatter. It does not sound plausible that the Universe just started with such asymmetry. It is hypothesized that this asymmetry was generated at some point in the history of the Universe. This process is called baryogenesis.

After the discovery of CP violation, the requirements for baryogenesis were listed up. One of them is the violation of C and CP symmetries [2]. CP violation is necessary to explain why there are plenty of matter out there, and why we humans which are, of course, made only of matter, can exist.

CP violation is still an important topic today. There are discoveries to be made and problems to be solved.

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[1] Technically, particles whose antiparticles are themselves survive, but most of such particles alone cannot form matter. Anyway, such a scenario does not result in the Universe we have.

One of them is that the laws of particle physics may have different forms of CP violation than the ones I introduced above. Many experiments are planned or already running to find them. For instance, the T2K experiment in Japan is probing a new type of CP violation through particles called neutrinos [3]. Projects all over the world are trying to provide a new insight about CP violation.

In fact, successful baryogenesis requires a new form of CP violation. Currently observed CP violation can account for only a small part of the matter-antimatter asymmetry [4]. Consequently, the mechanism of baryogenesis is yet to be known. In the future, physicists may solve the mystery of the matter abundance and hence, our existence.

Another mystery about CP violation is that a type of force called strong force is known to have little or no CP violation for seemingly no reason [5]. Given CP is violated in other parts of the physics, physicists suspect an unknown mechanism for this.

Depending on results of future research, it might turn out that the Standard Model, the "default model" of particle physics, must be largely modified. Many extensions are already suggested and discussed. CP violation might provide a hint for these new, deeper descriptions of this world.

CP violation is an essential part of the fundamental physics and the history of the Universe. Research on this direction would eventually uncover answers to these mysteries about the world.

References

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