APCTP People:
Mass vs. Symmetry

Sun Kun Oh

Every student who has attended physics class in their school days might have encountered, perhaps for the first time, the concept of mass while learning the Newtonian laws of motion; mass appears as a proportion coefficient between force and acceleration. In everyday life, mass is commonly confused with weight or inertia. Some students might have felt that mass is a very tricky and weird concept.

Students might also have been astonished that the unit of mass is extremely difficult to standardize, compared to the unit of time or with the unit of length. Any physical quantity is measureable in terms of mass, length, and time. It is well-known that the unit of time is now based on the duration of radiations of a specific atom, and that the unit of length is defined in terms of the unit of time and the speed of light. Thus, we need not refer our scale stick to the prototype meter bar, made of metal alloy, stored in France.

On the other hand, a universal method of defining the unit of mass, a kilogram, is practically non-existent. Any weighing scale in any country, precision or crude, should in principle ultimately be referred to an artifact, the International Prototype Kilogram, kept in the custody of the International Bureau for Weights and Measures.

Not only in everyday life but also in the highly theoretical field of the elementary particle physics, is the concept of mass therefore very important yet very elusive. It is actually problematic. Symmetry is one of the most fundamental concepts in modern elementary particle physics. However, symmetries cannot coexist with masses. If gauge fields have masses, then gauge symmetry is destroyed. Also, chiral symmetry is destroyed if fermion fields have masses. In other words, the masses for those fields should not be allowed, as long as symmetries should be respected.

It is basically a kind of dilemma between mass versus symmetry. One might call it a conflict or a contradiction. To strictly adhere to symmetry, one should discard mass. One cannot take both of them into his or her theory at the same time. Most theoretical physicists would prefer symmetry to mass, since mass is clumsy, irrational, and empirical. On the other hand, symmetry is beautiful, logical, and doctrinal.

Indeed, the basic structure of the Standard Model, regarded as the core of the theoretical framework of the elementary particle physics, starts without any mass term. Neither gauge fields nor fermion fields are allowed to have mass. Thus, the Standard Model describes presumably a massless but symmetric world. Well, this has been the situation before spontaneous symmetry breaking has taken place.

In reality, however, the world is massive and not symmetric: The gauge bosons and fermions have masses, and the gauge and chiral symmetries are broken down. It is true that principle alone cannot provide life for us; we should

The author has been the professor of physics at Konkuk University, Seoul, since 1980. He has received his Ph. D. degree for theoretical particle physics from KAIST. He has recently published two books, written in Korean, entitled "Basic Concepts of Supersymmetry" and "A Personal Discourse on the Standard Model."

live with reality. Therefore, we should break symmetry in order to embrace mass. The procedure to introduce mass into the Standard Model is called spontaneous symmetry breaking, or, simply, the Higgs mechanism. The entire procedure is led by scalar fields.

The introduction of scalar fields to the Standard Model has been provided by Peter Higgs and other five physicists, who shared the 2011 Sakurai Prize for their efforts. At the time of introduction, scalar fields seem to obey symmetry, as they have been massless, too. Once inside the Standard Model, the scalar fields have arguably revealed that, in terms of a particular potential form, the vacuum should be redefined. This is the start of the Higgs mechanism.

The redefinition of the vacuum triggers the spontaneous breaking of symmetry. The symmetry of the Standard Model is finally broken down and mass is successfully introduced. The scalar fields, as well as the gauge fields and the fermion fields, take possession of the masses, for the victory. Well, not all of them have been lucky. Some of the fields could not acquire masses.

The spontaneous tumbling down of the symmetry seems, at least to me, the story of a coup *d'etat*. In some sense, the word 'spontaneous' is very implicative and metaphorical. Thus, the Higgs mechanism might be regarded as a kind of sociopolitical procedure in the elementary particle physics. The experimental confirmation of the existence of the Higgs particle, probably due in the next few months at LHC, might put an end to the dominance of symmetry in the Standard Model for good.

Since Gell-Mann has suggested the 'Eightfold Way' in his quark model almost half century ago, a variety of symmetries have been introduced in the elementary particle physics. However, almost all of them, from the eightfold way itself to supersymmetry, have been broken, either partially or completely, in due course. Indeed, for theoretical physicists, symmetry is too beautiful not to grasp. "Symmetry first" has been a catchphrase for them. But, inevitably, reality should be embraced for physical theories to describe the real world. Mass has been, and will be, the most serious Achilles' heel for those theories.

I have had a few occasions to advocate my opinion in a number of workshops, but the audience has not been in enthusiastic accord with me. Dear readers, I would like to ask you for your points of view on the Higgs mechanism.