Symmetry: What makes the world what it is

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There is no doubt that the 20th century is an explosive time for the development of physics. The experiments and theories compete and inspire each other, leading to more progress than ever. Even just as junior high school students, you must have heard of some splendid Odysseys and shining names, like Einstein's discovery of general relativity. Or at least you are benefiting from the technologies based on these developments. For example, the chips in the computer and smartphone you use daily are running based on quantum mechanics.

However, when you try to look at what happened in 20th-century physics, you might get lost at first. There are so many of them: relativity, quantum mechanics, quantum field theory, solid theory… They look quite scary. Nevertheless, if you are brave enough to dive into an exploration of this whole building of physics, you will finally find a main essence in between the symmetry principle. It is no exaggeration to say symmetry is THE thing that leads us so far away.

So what is symmetry? I believe you have been quite familiar with this concept due to your life experience. For example, you know that the shape of a ball looks invariant no matter how you rotate it, which is called rotation symmetry. You also know that your image in the mirror is the same as you except for a reverse of left and right, which is called parity symmetry. Symmetry is preferred by nature even at the macroscopic level.

It is widely believed, at least according to the observation of humanity so far, that the microscopic world should also enjoy such a symmetry principle. For example, we should believe that the physical laws themselves should never change no matter where and when we do the experiments. This is called spacetime translation symmetry. The development of modern physics, roughly speaking, is nothing but about expanding our understanding of the concept of symmetry, and combining them with some general physical theory framework. The combination of Poincare symmetry and classical physics leads to relativity, while that between internal symmetry and quantum theory leads to standard models, etc. The real power behind symmetry is that it imposes strong constraints on the system so that the system will give some highly regular and general behaviors.

To make an analogy on what's happening here, imagine you're trying to draw a geometrical curve on a paper. If I don't give you any requirements, there will be infinite possibilities that can never be exhausted. But if I tell you that the picture should be symmetric concerning the middle line of the paper, then you only need to draw a picture on half of the paper, and then copy it in an inversed direction on the other half. Further, if I pick a point from the paper and tell you that your picture should be rotationally invariant concerning this point, then actually the only choice is to draw a circle! The only thing you can control is its size. Modern physics is basically about doing such kinds of things: you impose some general symmetric principle inferred from experience or assumption and then try to “draw a picture” in the abstract world composed of different possible theories. The more symmetries you have at hand, the less freedom you will have. Finally, you might obtain a theory with only a few parameters you can change, like the size of the circle in the previous example. In this sense, we will get something simple and regular. It is widely believed that our world is strongly constrained by the symmetry principle at a very small scale ($<10^{-35}$ m) so the possible behaviors are quite limited. This belief fits not only with aesthetics but also with many experimental observations. So understanding symmetry is very important.

The power of symmetry is so strong that it fascinates physicists until today. Nowadays, at the cutting edge of modern physics, we found a new kind of symmetry that exists in theory, called generalized symmetry. As the name shows, it generalizes the normal concept of symmetry in several aspects. For example, traditionally people think basic particles are points, so symmetries can only act point by point. But generalized symmetries might act on line-like or surface-like objects. Further, they might also be non-invertible, that is, you can never completely cancel their effect by some other symmetry operations. For example, imagine you have two opposite mirrors. From experience, you would expect the image after double reflection to be the same as the real world. This is normal symmetry. But in the case of a “generalized mirror”, the image might be twisted and no more the same as the real world! With these powerful new weapons, we can understand some mysterious physics phenomena much better than before. There are a lot of open problems of interest, for example, can we classify all different possible generalized symmetries? How can we identify generalized symmetry in a given system? How such symmetries will constrain the behavior of the system? My work is basically about clarifying these concepts with some concrete models.

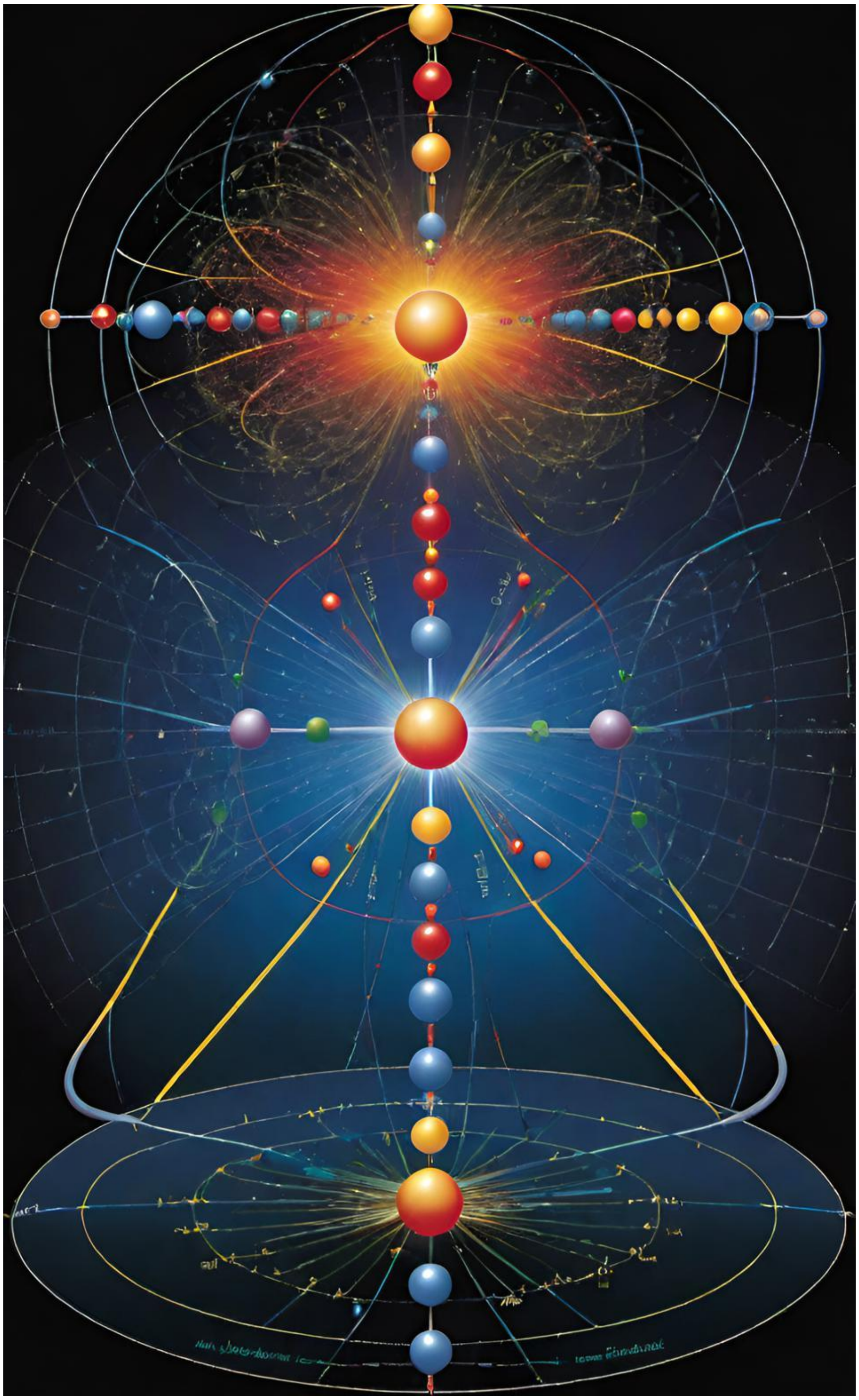
You might ask, why am I interested in this area? It sounds like an abstract intelligent game that will never contribute to real life. In some sense, you’re right, and this is exactly one of the embarrassing points of modern theoretical physics. No matter how physicists try to convince the public how valuable their work is, it is still a fact that most of the work might just be a pure interest in a very small group of people. So, why are we still doing all of this?

I, just on my own, would like to tell you my private answer to this problem. The study itself has 2 aspects, process and result. For most people, studying is something that finally serves their target: maybe to find a good job, maybe to improve their ability, or even to make a great contribution to some field to be memorized in history. I absolutely mean nothing negative here, these are all good enough reasons for study. Finally, a person is a social element, and any behavior should work for some social reasons.

However, for some of those who might get interested in theoretical physics, like me, the situation is different. There appears some kind of alienation, or inversion, in their mind. To be concrete, they inverted the priority between the process and result of study so that they could feel a kind of pleasure from learning, thinking, and understanding themselves. This is not hard to understand, just like those who like running or hiking. Most running or hiking lovers would not expect to become professional athletes, they're just enjoying the pleasure from this physical process. Our situation might be exactly similar, but the only difference is that we're lucky enough to have a chance to earn our living while enjoying our mind process. Therefore, here comes my answer: I hope to become a physicist, purely because I feel this kind of pleasure from what I'm doing. I easily get bored with most kinds of entertainment, but physics is something that can always provide new enjoyment for me when I learn and understand new things.

The new concept of generalized symmetry attracted much attention from working physicists. They're not purely mathematical games, but rather we have had quite a lot of physical examples that have not been well understood for a long time. The new tool of generalized symmetry helped us understand much better the internal structure behind those mysterious physical effects and inspired us to extend the borderline of our knowledge further.

The research of generalized symmetry is still quite young and it is hard to predict its far future. At least for now, it is improving our understanding of many existing physical models. There is one final dream of modern physics, called “grand unification”, which means that we hope we can describe the whole of nature with a simple symmetry structure, and derive all the real symmetry structures from this unified model. Such trials didn’t have great success in the past decades, but maybe we can expect that the new expanded concept of symmetry can provide new possibilities. This is just an expectation; it doesn’t matter so much to most of us whether or not it can be realized. After all, as I have mentioned, thinking and understanding itself is enjoyable enough for most of us.



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