AN HISTORIC MOMENT IN PHYSICS

by RICHARD P. FEYNMAN

Experiments at Columbia University have now proved one of the basic laws of physics to be false—the principle of reflection symmetry. Herewith, some comments by a Caltech physicist on the importance of this radical reversal.

THE MOST USEFUL generalizations and the most appealing to the human mind are principles of symmetry. So the physicist holds very dear the principles of symmetry which he has discovered in the basic laws of nature. One of these is the principle of reflection symmetry. It says this: If an apparatus is built and operates in a certain way, then another apparatus built in every respect reflected (that is, bearing to the first in all its parts the relation of right to left hands) will behave in precisely the corresponding reflected way. So, if Alice really went through the looking glass, she would find the world in no respect changed.

Another way of putting this is to say that in physical laws there is no way to define absolute right or left. Of course one can use local geography (facing San Francisco from Los Angeles the ocean is on the left)—but imagine trying to tell a being on another planet (who—suppose—can see nothing we can see or point to) which side your heart is on.

You might object that right hand rules are used in magnetism, for example. The north pole of a magnet formed by a coil through which a current flows can be determined by using a rule involving one hand. Alice in the looking glass would call it a south pole, but that makes no difference, for if she went on figuring which way wires would be moved by the magnet, she would have to use her rule again and would come out correctly. In other words, north and south magnetic poles cannot be defined absolutely either (except by geography again). In the reflection symmetry the pole names would be interchanged.

All the laws discovered until a few weeks ago conformed to the principle—electricity, magnetism, gravity, atomic physics, nuclear physics, etc. But recently two experiments have been performed to show that it is false.

Miss C. S. Wu, at Columbia University, in collaboration with Ambler, Hudson, and Heyward of the low temperature laboratory of the Bureau of Standards, detected electrons which were emitted by radioactive cobalt nuclei (of atomic weight 60) when these nuclei, which act as little magnets, were lined up in a strong magnetic field at low temperature. They found more electrons were emitted toward the north pole of the magnet than the other way around! This permits an absolute definition of the north pole of a magnet, namely that toward which Cobalt 60 emits its electrons preferentially. It violates reflection symmetry.

We can tell our being on the other planet to try the experiment and find the north pole of a magnet. Then, if he has made a model of a man and wants to know where to put the heart, we tell him this way: Set the model so the cobalt emits the electrons foot to head (so that the magnetic field goes head to foot), then let a current of electrons in a wire go from the face to the back of the head. The wire will be pushed to the left, where the heart goes.

Another experiment performed by Garwin, Lederman, and Weinrich with the cyclotron at Columbia shows the same breakdown of reflection symmetry a little more indirectly. They measured electrons emitted by mu mesons (a particle 210 times the mass of the electron) and found a similar directional effect. But here the mesons weren't lined up by a magnetic field—they must have been produced spinning around an axis in their direction of motion. In this case the production process (the disintegration of another particle, the pi meson—276 times as heavy as an electron—yields the mu meson) must also violate reflection symmetry. So, in the last weeks we have found three processes which are not symmetric for reflection—the disintegration of Co 60, the disintegration of pi into mu, and of mu into electron.

The story behind these experiments is interesting. Among the new strange particles recently found there were two—one called the tau, which disintegrated into three pi mesons; the other called the kappa, which disintegrated into two pi mesons.

The tau and the kappa had the same charge, the same mass within the accuracy of measurement (2/10 percent), the same lifetime before decay, and were always produced in the same proportion. This series of coincidences could easily be explained if the tau and kappa were actually one and the same particle, but this possibility was disproved by invoking the law of reflection symmetry. In quantum mechanics it has a consequence called the conservation of parity, and it would violate this law if the same particle could disintegrate, in the manner found, into three and also into two pi mesons.

Repealing the law

At a conference on these matters last April in Rochester, Martin Block, an experimenter from Duke University, made the suggestion that all these miraculous coincidences would disappear and the (apparently) two particles could be one by giving up the cherished law of reflection symmetry. In the intervening months, C. N. Yang of the Institute for Advanced Study at Princeton University, and T. D. Lee of Columbia University studied this possibility extensively and proposed a number of experiments to test it. These were two of the proposed experiments. Parity is not conserved; reflection symmetry is indeed untrue.

Yang and Lee and, also, L. Landau in Russia, have made a special suggestion to describe the way that the symmetry may be lost. They point out that in each case (Cobalt 60, the pi decay, and doubly in the mu decay) a neutrino is emitted. Perhaps the culprit is the neutrino. Neutrinos carry spin angular momentum and previously (to preserve reflection symmetry) were assumed to be capable of spinning right or left around their direction of motion. Yang and Lee suggest that they can in fact only spin one way (say clockwise, as they approach). So far, all of the data of Wu et al, and of Garwin and Lederman, can be interpreted this way. Soon further tests will be made.

But this cannot explain all cases of the failure of the law, or otherwise we are back where we started, for there is no neutrino involved in the decay of the tau (or kappa).

What next?

Where do we go from here? We have many symmetry laws, and all become suspect now. We recently had a confirmation of one (called charge symmetry) with the discovery of the anti-proton. Each particle has a counterpart in nature, with all properties the same but with some signs reversed (for example, electrical charge). When the two meet they annihilate each other.

Electrons have, as counterpart, positrons—discovered by Carl Anderson here in 1932. Protons and neutrons have anti-protons and anti-neutrons, respectively. Corresponding to ordinary atoms one can imagine anti-atoms (with the protons, neutrons and electrons replaced by anti-protons, anti-neutrons and positrons), and ordinary matter should have a counterpart in anti-matter. The law of charge symmetry says that any apparatus built entirely of anti-matter should behave the same way as its counterpart built of ordinary matter.

Previously we had four possibilities, all behaving alike—the original apparatus; its mirror image; the apparatus of anti-matter; and the mirror image built of anti-matter. All should have behaved the same, but we have now learned that the first two differ. The last two must now differ too, but which corresponds to the original?

The preliminary experiments all indicate that there is still one element of symmetry left: the original apparatus and the mirror image of anti-matter should agree. That is, the being on the far planet would get the heart on the correct side if he is made of the same stuff as we, but if he is made of anti-matter, he will make his model with the heart on the wrong side if he follows our directions. And there is no further way to tell him whether he is made of the same kind of matter as we, or of anti-matter. We shall see how long this symmetry principle lasts.

This is an historic moment in physics. During the last three decades we have been learning about many new things; but not, until now, that an old thing was wrong. Now we have to give up a cherished symmetry, and nature looks more complicated to us than ever. But the great progress always starts by the undermining of old ideas, and the loss of this one lets a host of new ones out to be tried. We have confidence, judging from the past, that what looks like a complication today is the first step toward a greater understanding and simplification in the future.