On the way to Neutral Weak Currents

by Dietrick E. Thomsen

In recent months particle physicists have become excited about experiments that demonstrate the existence of a phenomenon called neutral weak currents (SN: 5/4/74, p. 284). The excitement is concerned not merely with the discovery of a new and rare type of behavior of "elementary particles," significant as that alone may be, but because the findings go to prove a new theory that unites two of the four kinds of force that physicists recognize, the weak force that operates in the doings of subatomic particles and the electromagnetic. The new theory represents a step on the way to a consummation devoutly hoped by many physicists, a unified field theory that would unite all four of the forces and show them to be different aspects of one and the same thing. (The other two forces are the strong force that binds atomic nuclei together and gravitation.)

One of the people who has been quite prominent in development of the theory is Steven Weinberg of Harvard University. At the invitation of the Optical Society of America Weinberg recently gave a review of how the theory developed. It is not always easy to follow the thought processes of theoretical physicists in cold words, but what we have here is a retrospective of an important current in theoretical physics.

The starting point is to think of light as an elementary particle. The uniqueness of light as a physical phenomenon has been a subject of comment ever since the writers of *Genesis* made it the touchstone of getting order out of chaos, being out of nonbeing. Contemplation of the wave nature of light has generated an entire branch of physics, physical optics, which is the bread and butter of that Optical Society that invited Weinberg to speak. But we put this aside and concentrate our attention on the other aspect of light, its particulate nature. Think of light as photon, as one of many elementary particles, a participant with them in the continual round of generations, absorptions, transmutations, rotations, collisions and interactions that characterize existence in the subatomic domain.

Weinberg: Seeing light as a particle.

If we do this we can begin to think of the photon, not as something unique in physics, but as one member of a family of closely related particles with similar functions. Such a mental step is not speculation for the sake of speculation. It connects to a train of thought that proceeds from one of the important simplifying principles of theoretical physics.

Physicists, especially theoretical physicists, are always happy when they can simplify. If they can sum up a large number of seemingly disparate phenomena in a simple theoretical statement, they are overjoyed. Maxwell's equations, for example, are a milestone in the history of theoretical physics. James Clerk Maxwell was able to sum up in a small group of equations all the ways and means of electric and magnetic behavior (including the wave nature of light).

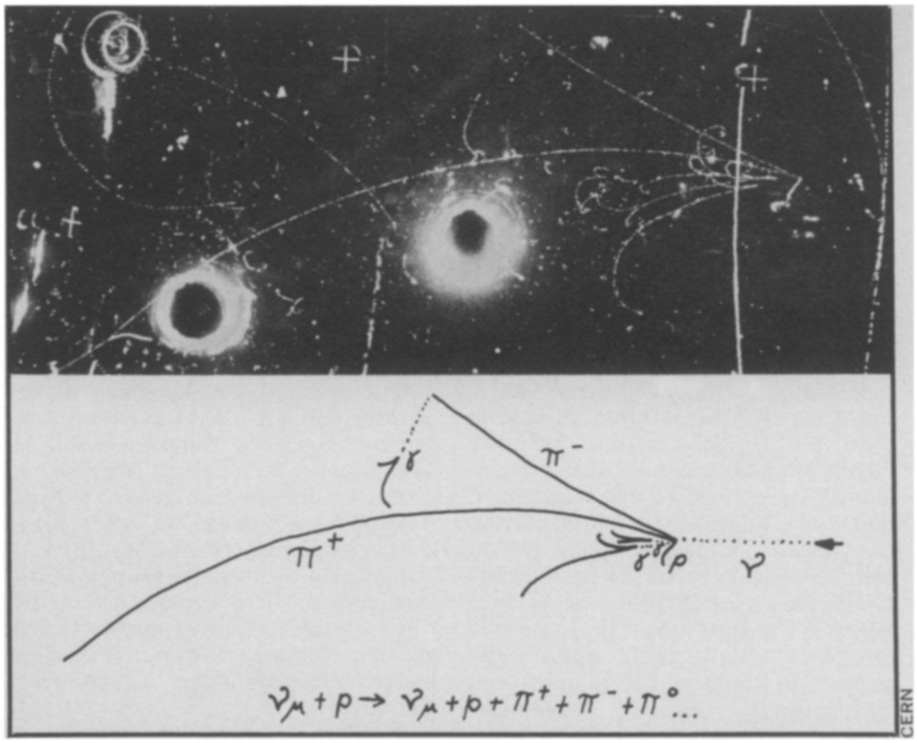
Maxwell's equations look even simpler in modern notation than they did in the notation current in his time, but behind them lies a more basic unifying principle, which physicists and mathematicians call gauge invariance. Gauge, says Weinberg, is usually defined as having to do with the way you measure distances, but in this context that definition is both vague and misleading. Mathematically the idea is clear to those who can read the mathematics; verbal description is halting.

Invariance is an easier term. We say that a set of mathematical equations is invariant if we can perform certain transformations on our point of view and the form of the equations stays the same. The equations of special relativity do not change their form if we move (translate) our point of view from one observer to another at a different point in space and time. (The numbers that go into them may change, but their mathematical form does not.)

The gauge invariance of the electromagnetic equations is not a space-time symmetry like the translational invariance of special relativity. It is rather a symmetry principle internal to the equations themselves, a symmetry that acts on the labels we give to particles. The form of the electromagnetic equations does not vary if we perform transformations related to this kind of symmetry. "The laws of electromagnetism can be summarized in a statement of gauge invariance," says Weinberg.

A paragraph aside to indicate that we are not being vague for the sake of vagueness. It is that while the mathematics is clear, words are an uncertain guide to describe it. Anyone who has studied mathematics will remember that the farther you get into it, the more you talk in symbols. Words do not stretch far enough, and if words are used, they are coinages *ad hoc* whose meaning is defined by the symbolism and not the other way around. Physicists do not speak in mathematics in order to mystify but because they must. It was with a certain shock of recognition that we came across an essay by Lawrence LeShan, former chief of the department of psychology at Trafalgar Hospital and Institute of Applied Biology in New York ("ESP" in the May INTELLECTUAL DIGEST),

A sketch of recent developments in the theory of the weak interaction



Neutral weak current interactions first appeared in experiments at CERN.

in which the author argues that physicists, like mystics, have penetrated to a mode of consciousness that transcends the ordinary. Mathematics, like contemplative meditation, is a way to a mode of perception that apprehends reality in ways difficult to explain in the terms of ordinary sensory perception. LeShan cites such ideas as the wave-particle duality and the uncertainty principle and quotes prominent physicists (Einstein, Heisenberg, Bohr, de Broglie) in support of his expanded consciousness proposition. If this sounds like paradox as the outcome of an investigation that began centuries ago by rooting itself in just those terms of ordinary sensory perception, one must reply that the physical doctrines just cited are also paradox as are most of the beliefs people live by.

So much for metaphysics. Back to the physics.

Physicists love great overarching simplicities. They like to drive an idea as far as it can go and see how many different phenomena can be gathered under one umbrella. Therefore arose the question: Given the gauge invariance of electromagnetism, can one devise a statement of gauge invariance so broad that it will include other phenomena besides the electromagnetic?

It turns out that such a formulation can be made, and it was made as long ago as 1954, but it had a rough time at first. It predicts that the photon is accompanied by related particles having positive and negative electric charge, zero mass and one unit of spin (the photon is electrically neutral). Such particles were never discovered.

The formulation also coupled to a speculation by Hideki Yukawa that the photon, one of whose functions is to carry electromagnetic forces from place to place—it embodies the forces so to speak—was analogous to a particle that did the same for the so-called weak force, and that the analogue was part of the photon's extended family. The theory predicted that the weak-force particle, usually referred to as the intermediate vector boson or W particle, would have an enormous mass of about 50 billion electron-volts and would appear in two kinds, with negative and positive electric charge.

Here was an intellectual stumbling block. If the principle of gauge symmetry, which has to do with the identities of particles, was operating, how could such a particle be related to the photon? Fifty billion electron-volts is more than 50 times the mass of a proton, some two dozen times the mass of any particle that has yet been identified. When it is compared with the zero mass of the photon, it seems even more absurd. Surely the particles closely associated with the photon should have properties analogous to the photon's. Furthermore if one calculated a possible interaction in which two W's were exchanged between a pair of particles, infinities appeared. Infinities are the kiss of death to a physical theory. The whole business was characterized as "nonsense."

In 1967 Weinberg found a way through the dilemma. He applied to the weak interaction theory a principle called symmetry breaking that had been used in other branches of physics. It means that though the laws have symmetries, the symmetries are not phenomenologically apparent. We must infer them. "Particles as they are distort symmetry," says Weinberg. The very existence of particles breaks the symmetry of the natural laws.

With a spontaneously broken symmetry, the W particle can have a mass far out of line with that of its analogue the photon. The infinities disappear and a believable theory of the weak force, one that links it with electromagnetism, comes out. The photon, the W particles positive and negative and a new one, the electrically neutral Z particle, form a family of particles of similar function.

It is the Z particle that is involved in the experimental excitement. Like the W's it is a carrier of the weak force. Its existence permits two colliding particles to interact with each other under the aegis of the weak force without exchanging electric charge. In the past, with only charged intermediaries available, such an interaction had to exchange a unit of charge between the particles involved. Now it need not.

"The model is working out well experimentally," says Weinberg. The mass of the W's would seem to be about 50 billion electron-volts with a lower limit of 37 billion electron-volts firmly established. If the arithmetic is done right the rates at which neutral exchanges occur compared to those at which charged exchanges occur come out within the data of the experiments.

Theorists are now at work trying to fit the strong nuclear forces into the scheme. For the moment gravitation must stay out. It is the old problem of infinities. "Something is wrong with Einstein's formulations on the small scale," says Weinberg. Eventually, however, this difficulty may be overcome, and a truly unified field theory may develop.

"Nature is simple," says Weinberg. The task of the theoretical physicist is to show "how diversity follows from simplicity." □