Axion Hunt: Getting Something Out of Nothing

Physicists have been described as people who try to make reality out of mathematical abstractions. So be it, but occasionally one begins to wonder exactly where the boundary between being and unbeing lies in modern physics. The old-fashioned physics was full of absolutist definitions: Matter was matter; emptiness was emptiness. Space was one thing, time another. Waves were one phenomenon; particles were quite different. Mixing opposites led to paradox, and paradox was illogical.

The old physics had hard and fast sayings, usually expressed in Latin: *Natura non facit saltum. Natura abhorret vacuum.* The one about nature not making jumps has been shot thoroughly to pieces by modern physicists, but the one about nature abhorring a vacuum seems to be coming true — in a way its framers never intended. It's not that matter rushes in to fill an emptiness; it's that there wasn't really an emptiness in the first place. The vacuum is full of things — or rather not quite things, the solutions of equations really — called instantons. If these are not quite material, they have important effects on the most fundamental behavior of matter, and their existence — if it can be called that — demands the existence of a particle, the axion, that is material enough to be looked for in an experiment. An experiment to look for axions was run recently at the CERN laboratory in Geneva. It didn't find any, and so already some commentators are saying that maybe the theory needs a new formulation. To continue in Latin, *sic transit gloria mundi.* But that's not likely to be the end of the story quite yet. Someone else is sure to search for axions right soon.

The old physics proceeded by *a priori* reasoning. Modern physics is an existential philosophy. If something works in one place, try it in another and see if it works there. The story starts a couple of existential steps back with the theory of quantum electrodynamics.

Quantum electrodynamics is the theory of electric and magnetic behavior on the subatomic level. It has been one of the smashing successes (possibly the only smashing success) of modern physical theory. It makes numerical predictions that are brilliantly satisfied by experiment. One of the recreations of the sort of people who like to calculate pi to 1,000 significant figures is designing new experiments to test quantum electrodynamics. If they have not knocked a serious hole in the theory, they have done a great deal to develop the precision of modern experimental equipment.

At this point one can almost see the neurons in physicists' brains firing. The reasoning goes by analogy. Since the formalism of quantum field theory works so well for electromagnetism, why not try it on the force, called the strong interaction, that binds quarks together to build up protons, neutrons and a hundred or more other particles of the class called hadrons? Of course there is a great difference in the observational status of the two theories. No one has yet found direct evidence of the existence of quarks or of the force that binds them; direct evidence of the particles and forces of electrodynamics is available at the flick of a switch. But there is a lot of secondary evidence for the quark hypothesis.

It turns out that there is an important theoretical difference between quantum electrodynamics and quantum chromodynamics, as the theory of the quark force is called. A quantum field theory needs a charged particle to be the source of the field forces — in electrodynamics that's the electron or alternately some other electrically charged particle — and a field quantum or intermediate particle by which the charged particles interact with each other. The field quantum of electrodynamics is the photon. When electrons exchange photons, a force appears between them. In chromodynamics the charged particles are the quarks. Their charge is called "color"; hence the word chromodynamics. (For more detail about chromodynamics, see SN: 6/26/76, p. 408.) The field quanta by which the quarks interact are called gluons.

Here comes the complication. In electrodynamics the photons interact only with electrons; they do not affect each other. Gluons, however, do interact with each other, and they need something to interact by. That turns out to be instantons. Instantons are nothing so simple as another level of field quanta. In a review of the subject in the March 30 NEW SCIENTIST, James Dodd of the Cavendish Laboratory at Cambridge University in England calls them pseudoparticles.

Instantons are solutions to the mathematical equations that describe the forces of chromodynamic field but, unlike field quanta, they have no materiality. "They are not particles and have no direct physical interpretation," Dodd writes. They are properties of the vacuum, and since a vacuum is defined as a state of zero energy, there is no question of material objects there. Instantons are mathematical, but they have a physical effect: In their presence the gluons feel forces. So nothing can affect something.

The vacuum thus contains mathematical beings that teeter on the edge of reality and affect the behavior of material objects, starting with the gluons and working outward until, quite literally, the green grass grows all around. Furthermore, the introduction of instantons requires the existence of a new particle that should be quite material, the axion. While the instantons seem to be the way to solve a number of important difficulties in quantum chromodynamics, including the tantalizing question of why the quarks seem to remain always bound inside the particles they build and never go free, they raise other problems.

As in many other cases in theoretical physics a patch put on in one place causes a rent in another. In this case the quark masses no longer add up properly to make the particles that are known to exist. An analysis of the problem by Steven Weinberg of Harvard, one of the developers of quantum chromodynamics, led him to suggest the existence of a very light particle, something between a hundredth and a tenth of the mass of the proton. Axions ought to show up in the collisions of neutrinos with protons. An experiment to look for them was set up at CERN. It is the one that found the strange neutrino behavior reported earlier (SN: 4/1/78, p. 196), but it didn't find any axions. Unlike some other recently hypothesized particles, axions ought to be easy to find. Repeated lack of success means finding some other way to get around the difficulties made by instantons or giving up the instantons. □

A 'plastic' cure for the mind's eye

The complex wiring system connecting the eyes and the brain winds through a galaxy of synaptic circuits synchronized by bursts of chemical signal-carriers. Deciphering any portion of this baffling highway might be akin to tracking a single particulate through the ecosphere of Los Angeles at rush hour.

But two California Institute of Technology scientists report that one brain chemical, norepinephrine, appears to play a critical role in the engineering and operation of the visual brain system. And they say the results of their latest experiments — performed just with animals thus far — might lead to reversal or prevention of "stereoblindness," or depth perception deficits, in humans.

Infant animals that have had one eye held shut during a visual learning period have become "imprinted: When the eye is opened again, the animals are unable to use both eyes to perceive depth in the visual space. Electrode implant experiments have shown that such animals develop significantly fewer cells connected