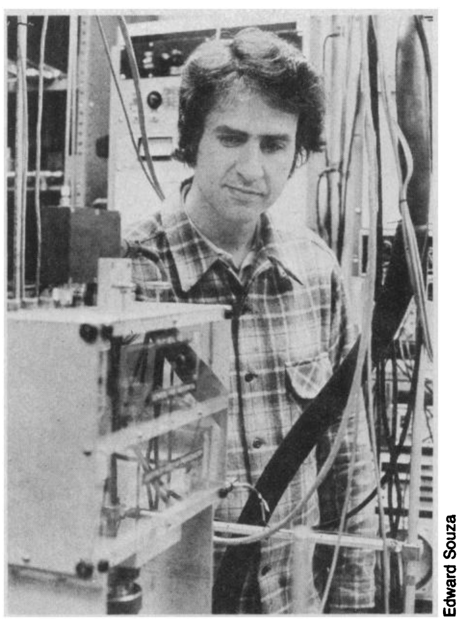
In Search of the Magnetic Monopole

A young Stanford researcher may have found the long-sought unit of magnetic charge; but he is as skeptical as anyone

Physicists have reacted to news of the Stanford magnetic monopole with excitement tempered by a large dose of skepticism. If real, the discovery of the long-sought unit of magnetic charge would verify a major prediction of the grand unified theories of particle physics, and would force people to do a lot of rethinking about astrophysics. But if spurious, it would not be the first time. Researchers have announced monopoles before, only to have others point out flaws in their experiment. As one physicist recently told *Science*, "[The Stanford event] is very interesting—but it sure would be nice to see another one."



Blas Cabrera

The news reached the public in April, as rumors of the finding became a dominant topic of hallway conversation at the American Physical Society meeting in Washington, D.C. From there the story leaped into the national press, and suddenly a 36-year-old Stanford University physicist named Blas Cabrera was surprised to find himself, however briefly, famous. Before his paper had even been accepted for publication (it appears in the 17 May *Physical Review Letters*), his picture was in *Time* and *Newsweek*.

In fact, there is probably no one more skeptical or more cautious than Cabrera himself. "Calling it a discovery is premature," he insists. "The experiment is not yet definitive. We've only seen one event in 185 days of running time. That makes it extremely difficult to do the kind of checks that one can do in a typical experiment." On the other hand, he says, "we've not come up with an easy way to explain the event away."

Cabrera is a bit irked by news stories that claim he built his detector all by himself in a basement, without government money. It is true that he had no specific funding for the detector, but the equipment and techniques he used were developed for projects funded by the National Science Foundation, the National Aeronautics and Space Administration, and the National Bureau of Standards. With those agencies under fire of late, he says he feels strongly about recognizing that support. He never seriously expected to find monopoles anyhow. They are thought to be quite rare in the universe, if they exist at all. He just wanted to demonstrate an idea for a detector and possibly set some upper limits on monopoles' cosmic abundance.

His idea was remarkably simple: essentially the detector was just a 5-centimeter-wide coil of superconducting niobium wire. It turns out that a monopole passing through such a coil will alter its circulating supercurrent by a predictable amount, independent of the monopole's speed or direction. Thus Cabrera needed to make no assumptions about the particle's mass or its ability to interact with ordinary matter, two unknowns that have clouded previous monopole searches.

He set up the detector in the basement of Stanford's Varian Laboratory, where it would run automatically for days on end. The event came at 1:53 p.m. PST on St. Valentine's day, 14 February 1982. No one was in the room at the time; Cabrera found the signal marked on the instrument's strip-chart recorder when he returned an hour and a half later.

It was by far the largest event the experiment had produced. "My first reaction was that it must be spurious," Cabrera recalls. He began to suspect otherwise after he had spent a week calibrating the jump in detector current. He did this three different ways, and each time the event came out with the right magnitude to be a magnetic monopole.

Cabrera's *Physical Review Letters* paper explains how he then spent another 3 weeks ruling out such spurious sources as line voltage fluctuations, radio-frequency interference, ferromagnetic contamination, and even earthquakes. He invited others down to his laboratory to give their opinion. Among them was L. Peter Trower of Virginia Polytechnic Institute. "The experiment is clean and elegant," Trower says. "If nature is playing a trick, it's one hell of a subtle trick."

Another visitor was Nobel laureate Luis Alvarez of the University of California, Berkeley, himself an old hand at monopole searches. "Of all the monopole signals I've seen in my life," he says, "this is the most convincing."

Cabrera, however, is not convinced. He points out that the system is sensitive to mechanical disturbances. He believes he can rule out external causes: even when he bangs on the detector assembly with a screwdriver handle, for example, he cannot produce a signal as large and as clean as the candidate event. But it is harder to rule out internal causes. The coil has four turns of niobium wire, he notes; perhaps the signal was actually due to the release of stresses that built up when the coil was being cooled to cryogenic temperatures.

To eliminate that possibility, Cabrera is now building a multiloop detector that will register a signal only if two loops respond independently (that is, only if a monopole passes through both loops). It will also have 50 times the effective area of the earlier instrument, and thus a much higher counting rate. He expects to begin preliminary cryogenic testing in June. As with the first detector, he has proceeded without specific funding, although he has requested money from the National Science Foundation and the Department of Energy.

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The physics of monopoles is by now a highly evolved branch of quantum field theory, but the basic idea is much older. In a magnet, such as a bar magnet, the field is concentrated on the ends. "North" poles attract "south" poles and repel other north poles. The similarity to positive and negative electric charges is obvious, so it seems natural to assume that the field arises from little north and south "charges" that have somehow collected on the ends of the bar.

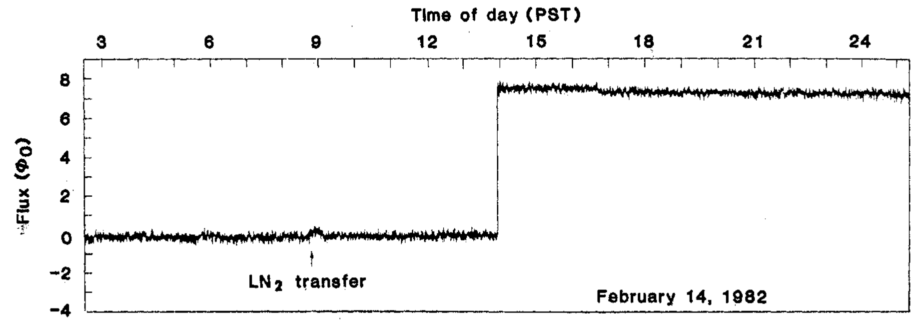
But there is one crucial difference. Electric charges can be isolated and stored in a Leyden jar, for example. Magnetic poles cannot be isolated. Break a bar magnet and two new poles appear at the break. The result is not two isolated monopoles but two new bar magnets.

All this was explained in the 19th century by James Clerk Maxwell's unified theory of electromagnetism: electric fields arise from electric charges (which we now know as electrons and protons), while magnetic fields arise from electric currents—electrons moving through a wire, for example. In a ferromagnetic material such as iron or nickel, the currents are generated by the spinning of atomic electrons. Thus there is no need for magnetic charges.

But neither does Maxwell's theory rule them out. The absence of monopoles is an empirical fact, not a logica necessity. In 1931 the monopole idea was explored in more depth by the British physicist Paul A. M. Dirac. Combining Maxwell's electromagnetism with quantum theory, which he had helped invent just a few years before, Dirac found that if magnetic monopoles existed their magnetic charge could not be arbitrary. It could only be an integral multiple of a certain number, which Dirac calculated in terms of such fundamental constants as the speed of light, Planck's constant, and the charge of the proton. That number, the minimum magnetic charge, works out to be about 70 times the proton charge.

Much more astonishing, however, was the obverse of Dirac's condition: if even one monopole exists anywhere in the universe, then every electric charge in the universe is quantized—that is, it must be an integral multiple of the charge on the electron.

The quantization of electric charge was another empirical fact, for which there was no other explanation. So physicists had to take Dirac's monopoles seriously. In the ensuing 50 years they searched for the objects with accelerators and they looked in iron ore. In the early 1970's Alvarez and his colleagues looked at moon rocks and even in sea bottom mud, where the monopoles might have collected over millennia. But nothing was ever found.



A monopole?

Cabrera's candidate monopole signal looms over a disturbance caused by a liquid nitrogen transfer earlier in the day. The jump in magnetic flux through the superconducting detector loop (or equivalently, the jump in the loop's supercurrent) is just the right magnitude to be a monopole. Moreover, the current remained stable for many hours afterward.

New impetus came in the mid-1970's, however, as Gerard 't Hooft of the University of Utrecht in the Netherlands and Alexander M. Polyakov of the Landau Institute near Moscow independently showed that monopoles need not be postulated ad hoc. They were, in fact, a natural consequence of the new unified theories that were proving so successful in describing the strong, weak, and electromagnetic interactions of particle physics.

't Hooft and Polyakov found that these theories contain certain kinds of quantum fields that can tie themselves into a tiny knot. The detailed properties of this knot depend on exactly which version of the theories one uses. But in the grand unified theories (GUT's), which unite all three interactions in a single mathematical framework, such a knot would contain an extraordinary amount of energy: it would look like a particle with a mass 10^{16} times that of the proton, or about the mass of an amoeba. Moreover, it would be quite stable. And, according to the field equations, it would be a magnetic monopole having one Dirac unit of either north or south magnetic charge.

So in the last few years the physics community has been taking monopoles very seriously indeed. (Ironically, monopoles are no longer needed to explain the quantization of electric charge; quantization falls out of the GUT's for quite different reasons.) But there is no conceivable particle accelerator that can produce a behemoth weighing 10^{16} times as much as a proton. The only hope of finding one is to look for a relic of the Big Bang, a monopole that formed when the temperature of the universe exceeded 10^{30} K.

Calculations based on GUT's and the standard model of the Big Bang indicate that both north and south monopoles should have formed abundantly during the first 10^{-35} second. As the universe expanded and cooled, many of these opposing pairs would have annihilated one another. But some would have escaped and, being stable, would have survived until the present. The question is where.

One prime possibility is that monopoles account for the "missing mass," that mysterious cosmic ectoplasm that astronomers have invoked to explain the dynamics of spiral galaxies and clusters of galaxies. (The spirals spin too fast. The galaxies in the clusters move too fast. In neither case is the visible matter enough to hold them together by gravity, so there must be some invisible matter, too.) Clouds of monopoles floating freely in space would indeed be invisible, since they would neither absorb nor radiate light very well.

Assuming for the sake of argument that monopoles account for all the missing mass, how many should Cabrera have seen? In his paper, Cabrera points out that the missing mass in the vicinity of the sun appears to contain roughly one-third to one-half as much matter as in the nearby stars. From that he estimates that interstellar monopoles should have passed through his 5-centimeter loop at the rate of 1 or 2 per year. He saw one event in 185 days, so on the face of it the missing mass interpretation looks reasonable.

But Cabrera also points out that other limits on monopole abundance are far less optimistic. The most stringent limit was put forth more than a decade ago by the University of Chicago's Eugene N. Parker. "The reason you don't find electric fields in space is because there are ions that neutralize them," Parker explains. "But you do find magnetic fields, so you can put a limit on how many magnetic charges there are." It would take a lot to neutralize the magnetic fields of the earth or the sun, he says. But the galaxy has a magnetic field too, and it is very weak, only 3 microgauss. "So you ask, how many free monopoles could you tolerate before they short out the galactic field?" His answer corresponds to a monopole flux of no more than 10^{-14} per square centimeter per second—about 10,000 or 100,000 times smaller than the flux implied by Cabrera's event.

"You have to be careful," says Parker. "Just because something upsets what you know doesn't mean it's wrong. Cabrera is a serious and careful man. But I don't think the Stanford result is a monopole."

The issue may not be in doubt much longer. Cabrera's new detector should be working soon, and other researchers will doubtless be trying to replicate his results with their own detectors. His result comes at a time of ferment in the field. In the April 1982 issue of *Scientific American*, Trower and his colleague Richard A. Carrigan, Jr., of Fermilab write, "The art of searching for massive monopoles is now at one of those engaging moments in science when a wealth of ideas, many of them quite bizarre, are at war on paper and over lunch tables."

A major problem is that no one is certain how monopoles interact with ordinary atoms. If one were moving near the speed of light it would certainly leave a trail of ionization. But monopoles are so massive they would probably move relatively slowly. (Parker estimates 300 kilometers per second.) In that case their magnetic fields would only mildly perturb the surrounding atoms. If a detector depends on ionization, slow-moving monopoles might sail through without doing a thing. Another major problem is that no one really knows where the monopoles are. They might be trapped in the iron core of the earth, for instance.

But suppose the Stanford event does turn out to be real. Cabrera, for one, will be both delighted and astounded. The grand unified theories will gain enormous impetus. And Parker, like many others, will go back to work with gusto—he expects to have fun figuring out where his astrophysics has gone wrong. "It's a very entertaining dilemma," he says.

—M. MITCHELL WALDROP

LEP Detector Competition Opens at CERN

The huge accelerator will have room for four experiments at first, each costing about $30 million and involving about 250 physicists

It was standing room only, and there was not much of that, in the auditorium of the European Organization for Nuclear Research (CERN) the morning of 24 March. Hotel space in Geneva, CERN's Swiss home, was scarce, as high energy physicists came in droves to hear the first public presentation of the proposed detectors for LEP, the gigantic electron-positron collider that the laboratory hopes to begin building by the end of the year.

Attendees heard pitches from seven groups, six of whom described detailed plans for mammoth particle detectors. Each of these beasts—no other word is appropriate—typically would weigh well over 2000 tons, would cost about $30 million, and would require the efforts of physicists from about 20 institutions. Attendees also heard CERN's directors paint a picture of a laboratory so financially strapped after building LEP itself that there will be relatively little left over for the winning detectors. In a reversal of past practice, the major financial burden will fall on the members of the experimental collaborations. Moreover, two of the would-be collaborations involve major U.S. participation. There is thus the interesting and unresolved double-sided question: how much of its expensive new machine does Europe want to leave open to American physicists and how much of its tight high energy physics buget does the United States want to spend overseas?

CERN secured the approval of its member states to undertake the LEP project last December, about a year and a half after formally submitting a proposal. To get the go-ahead, the laboratory had to convince the European countries that it could build the $500 million accelerator without an increase in its annual budget. It also had to get the member states to keep up their contributions to CERN, whose budget had been dropping in the late 1970's. However, lately it has been approximately constant before figuring in slight increases for Swiss inflation, and this year CERN is spending a total of about $340 million.

Construction has not yet begun, partly because of formal procedures required by the French and Swiss governments. CERN hopes to have all this cleared away by the end of the year and to begin signing the first civil engineering contracts, as well as ordering equipment, at that time. CERN's Director-General, Herwig Schopper, told the LEP audience that his goal is to have an operating accelerator with one or more detectors in place by the end of 1987. Perhaps the performance of neither the accelerator nor the detector(s) would be up to specs at first, but the idea is to have something running and improve from there.

The purpose of LEP, which is a circular machine of 27 kilometers circumference, is to allow physicists to explore in detail the energy region in which two of the forces that control the behavior of elementary particles, the electromagnetic and the weak, have comparable strengths. The weak force is weak in the sense that any reactions that can proceed by way of the electromagnetic or the strong nuclear force will take place before processes governed by the weak force. If elementary particles can be squeezed closely enough together, however, the weak force grows stronger. At collision energies of 80 to 90 billion electron volts (GeV), the electrons and positrons that circulate in opposite directions in LEP will be so tightly compressed that the weak force equals in strength the electromagnetic.

LEP, which may have a lifetime of 20 years or more, will be built in stages. The basic machine, to be completed by the end of 1987, is called phase one and is to have a collision energy of 100 GeV (50 GeV in the electron beam, 50 GeV in the positron). Ultimately, the energy could go as high as 260 GeV. The electron and positron beams are not continuous, but are in the form of packets or bunches a few centimeters long. With four bunches of each type of particle, collisions can

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