To Catch a Monopole

By DIETRICK E. THOMSEN

According to legend it took a virgin dressed in cloth of gold to capture a unicorn. No one has yet suggested such a procedure for magnetic monopoles, but one serious suggestion is a football field dressed in aluminum.

Second of two articles

Physics often seems to progress by a kind of dialectic. Physicists have a liking for symmetry. Given a situation that lacks symmetry, they look for means of providing it, but often the logic of the search drives them to an overbalance, and they are left in a new and different asymmetrical situation.

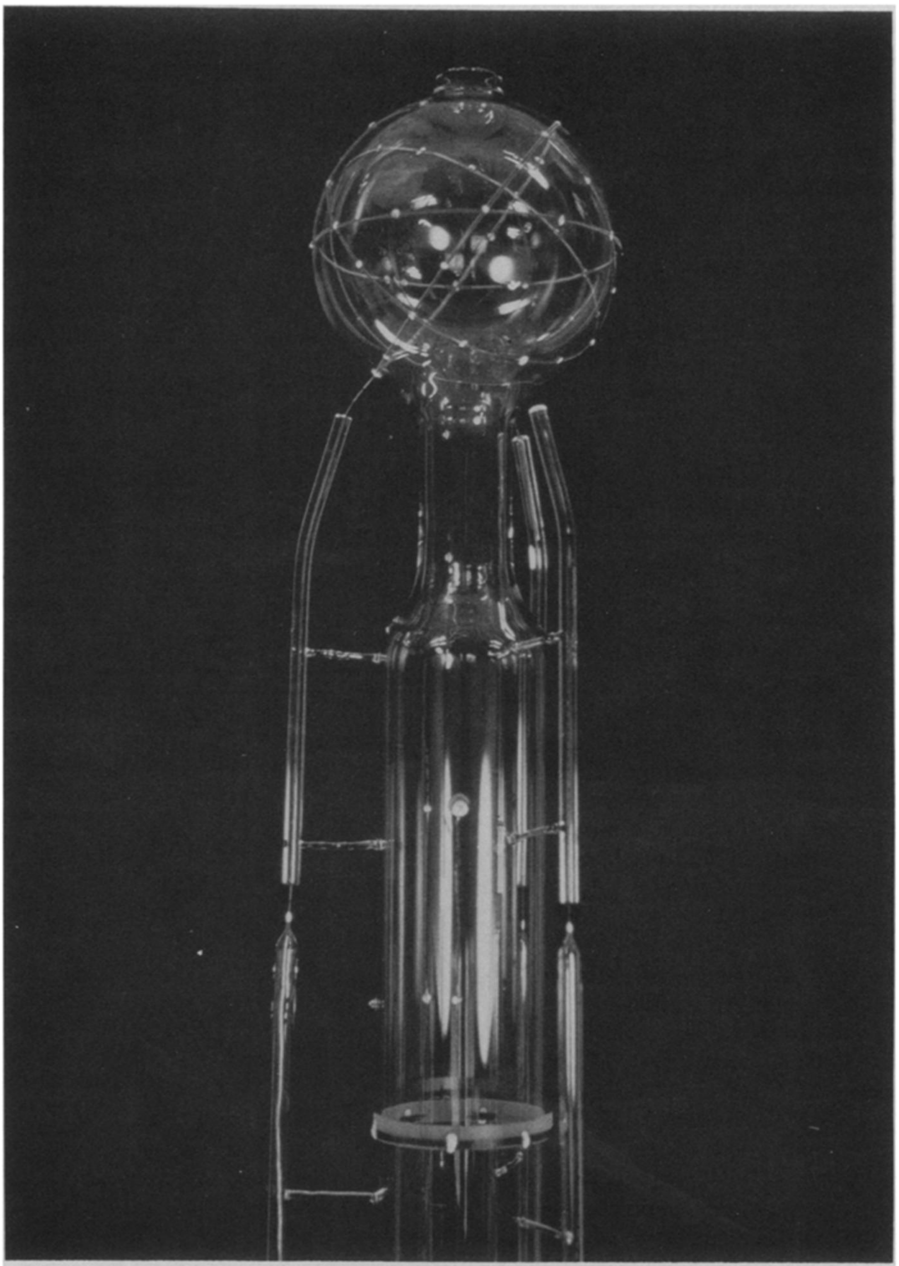
Magnetic monopoles are such a case. They were first intended to complete the symmetry between electricity and magnetism. Electricity and magnetism are reciprocal and symmetrical phenomena except that there didn't seem to be any magnetic correspondents to simple electric charges of one sign or the other, such as electrons and positrons. The smallest magnets always came with north and south poles inseparably bound together.

The search for a theoretical description of a possible magnetic monopole at first focused on a magnetic equivalent to the electron, a simple, point magnetic charge. However, the intervention of the new grand unified theories (GUTs), which are the latest attempts to unify all of physics in a single explanation, drove the situation way beyond balance. GUTs yield grand unified monopoles (GUMs), which are monster particles of a sort never before contemplated (SN: 11/27/82, p. 248).

Electrons with a mass of 511,000 electron-volts are the lightest things in physics except for two or three particles that have no rest mass at all. GUMs are by far the heaviest things ever called subatomic particles. Theorists think their mass should lie between 10^{16} and 10^{19} billion electron-volts. Electrons are supposed to be geometrical points or nearly so, simple unstructured things whose main function is to emanate electric forces. Originally theorists expected that monopoles would be the same, except for emanating magnetic forces in place of electric. GUMs, however, have a rich and complex structure that links them to a wide variety of phenomena beyond electromagnetism.

Even more important, the nature of GUTs brings GUMs to center stage. GUMs are one of two ways that physicists with their present capabilities can hope to find experimental evidence confirming GUTs. GUTs are extremely important. Generations of physicists have striven for such a unification of the science. With a very large part of it seemingly done in theory, experimenters are going to lose no opportunity to try to nail it down observationally.

The question of the hour is where to look for GUMs and how to try to find them. As the recent Magnetic Monopole Workshop, held at Racine, Wis., indicated, experimentalists faced with such an unprecedented quarry are groping more than a little. There are many disagreements and contradictory suggestions. A variety of



Stanford Univ.

Blas Cabrera (standing, below) describes improvements to his monopole experiment. His new apparatus has detecting circuits with three perpendicular axes (above).

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approaches is already being pursued, and many others will be added if money for them can be found. Eagerness is heightened by the reports of one and perhaps "one and a half" candidate events that might be monopoles. The "one" is an observation by Blas Cabrera of Stanford University of something that seems to have the proper magnetic charge for a monopole. The half is an observation by C.C. Tsuei of IBM that is neither quite right nor quite wrong. Everyone would like to be the one to give a definitive confirmation. On the other hand, the lack of agreement and of focus on particular experimental techniques became for some participants a mild damper on the enthusiasm with which they had arrived at Racine.

If GUMs exist, they should have been made when the universe was only 10^{-34} seconds old. Since then they have been somewhere, and the first place to think of looking for them is floating at large in the cosmos. There seems to be widespread agreement that they do survive. Giorgio Giacomelli of the University of Bologna in Italy remarks that few should be lost in the history of the universe. Michael S. Turner of the University of Chicago, who gave a kind of biography of cosmic monopoles, points out that within half a second after their formation GUMs should come to a thermal equilibrium in which their velocities are very nearly all the same and then should interact very little with other things down to our own time.

With this kind of a past monopoles should either be floating somewhere around the universe or stuck to or inside other objects. A physicist might think they could be in galaxies and clusters of galaxies. Unlikely, says Turner, for two reasons. Calculation shows that monopoles would not readily participate in collisions, and so could not convert their energy to heat in this way, which is a common process in many ordinary physical systems. In the technical term monopoles are nondissipative, and so they are unlikely to be found in dissipative, heat-producing material such as ordinary stars or the disks of galaxies. Furthermore, galaxies have magnetic fields, and so do clusters of galaxies. The fields would tend to accelerate passing monopoles so that their capture into the disks or halos of galaxies or clusters of galaxies is unlikely. The galactic fields would use up their energy doing the accelerating. And enough monopoles cutting through a galaxy would constitute a magnetic current that would tend to neutralize the galactic field.

If the extremely minuscule flux of 10^{-15} monopoles per square centimeter per second per steradian of sky (that is, one per 100,000 square kilometers in a second) comes through our galaxy, the galaxy's field would be destroyed faster than the dynamo processes that generate it could reestablish it. (Cabrera's finding would indicate a much larger flux than that.) Referring to the energy balances and exchanges in such processes, Turner says, "This is the new federalism: There's no free lunch."

Astrophysicists are certain that there is a galactic magnetic field. E.M. Purcell of Harvard University described it in great detail, and marshaled several lines of evidence to show that observation has measured its strength and its direction. He agrees that it would be difficult for the galactic field to capture passing monopoles. Even though cosmically created monopoles in thermal equilibrium move very slowly compared to the particles found at accelerators (at a few thousandths of the speed of light), their great mass gives them tremendous momentum, and they just go through things.

This "new federalism" is nevertheless opposed. Ira Wasserman of Cornell University in Ithaca, N.Y., represented the opposition with what he called "the radical portion of this program." That position is basically that the halos of galaxies are dominated by the galaxies' gravitational fields, not their magnetic fields, and so can capture a population of monopoles. These monopoles, sloshing back and forth, can generate a magnetic field. Thus, in this scenario, monopoles can cooperate with dynamo processes in generating and maintaining a galaxy's magnetic field, rather than destroy it. The disagreement between the two sides was far from resolved by the spirited discussion that ensued.

Turner also suggested some more exotic possibilities. Theory expects that grand unified monopoles will catalyze the decay of baryons into particles that are not baryons. Baryons (from the Greek word for "heavy") are a class of particles that up to now have exhibited a conservative family relationship: if a baryon decays radioactively, at least one baryon is found among the products; in any particle interaction, the net number of baryons does not change. Baryons include protons, neutrons and a large number of other varieties of particles.

This law of conservation of baryons used to be considered one of the basic principles of physics, but then came GUTs. GUTs require its violation. It used to be thought that the proton, as lightest baryon, was absolutely stable. There is no lighter baryon for it to decay into. GUTs, however, allow protons to decay into things that are not baryons. GUMs can catalyze such a decay by acting on the quarks that are found in the structure of protons and other baryons. A GUM would engulf a passing baryon and then spit out something that is not a baryon.

If GUMs have too much momentum to be captured by ordinary things, perhaps they can be captured by extremely dense objects with fantastically strong gravitational fields — neutron stars, for instance. Turner presents the picture of large numbers of GUMs living inside neutron stars, gobbling up passing neutrons and protons like so many cosmic Pac-men. Each swallow should produce a burst of X-rays of about a billion electron-volts energy. We might be able to detect these.

Detectable radiation from cosmic monopoles is also a feature of a suggestion brought forth by Christopher T. Hill of the Fermi National Accelerator Laboratory in Batavia, Ill. In this picture the cosmos originally produces monopoles and antimonopoles in linked pairs called monopolonium. Monopole and antimonopole orbit around each other, and after a certain lifetime (which can be billions of years) they come together and annihilate each other. Such annihilations would be continually popping off through the history of the universe. We might be able to see the radiation from them in telescopes like the Fly's Eye in Utah (SN: 8/2/80, p. 69), Hill suggests.

Finally there is a suggestion, alluded to by both Turner and Purcell and attributed to a group of astrophysicists known as the Harvard gang of four, that our solar system may be a region where the flux of monopoles is anomalously high, possibly eight orders of magnitude (100 million times) as much as the galactic average, says Turner. That is, the sun might capture monopoles into orbit about itself. If this is true, it could follow that monopoles were moving slowly enough with respect to planets or asteroids to be able to stick to something in those bodies.

None of these suggestions is by any means certain, and how likely any of them is, is a matter of sharp disagreement. "Feast or famine," says Turner. "Where are they [monopoles]?"

In the hope that they are somewhere, a variety of experimental techniques is proposed to look for them. One such technique, Cabrera's, already has a possible score (SN: 5/15/82, p. 323). A moving monopole constitutes a magnetic current. A magnetic current should induce electric fields in the space surrounding it. If a magnetic current threads a loop of electrically conducting material, it will induce an electric current to flow in that loop. Cabrera's first experiment consisted of a loop of superconducting material and looked for the sudden stepwise increase of electrical current that a passing monopole would cause. At IBM the experiment that has seen something that may prove interesting, according to Tsuei, uses nonsuperconducting electric loops to avoid certain phenomena in the relation between superconductivity and magnetism that the IBM physicists thought might confuse the issue.

In the laboratory where Cabrera works, which is directed by William Fairbank, an experiment running for more than a dec-

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ade has been finding what looks like fractional electric charge on little niobium balls (SN: 1/31/81, p. 68). Fractional electric charge is also something unexpected in contemporary physics. Cabrera's experiment was set up to see whether the niobium balls also show evidence of magnetic charge. They haven't, but on February 14, 1982, came the "standard event," which seems to represent some kind of cosmic monopole passing through. Or it may if nobody kicked the equipment at that moment or dropped a wrench on it. Rigorous investigation seems to show that that is not the case, but the experimenters would certainly like to see more events. So far they have not, but the running time up to the date of the monopole workshop coupled with the one event suggests that the flux of monopoles in this neighborhood is equal to or less than 1.2×10^{-10} per square centimeter coming from each steradian of sky per second. This is about 100,000 times the Parker bound, the limit mentioned earlier, above which the galactic magnetic field ought to be destroyed.

Cabrera has refined his experiment so as to give it a three-dimensional quality, by which it can test a larger volume and a greater variety of possible monopole trajectories. The new version is an evacuated glass globe on the end of a glass tube. Around the inside of the globe are laid three loops of superconducting metal at right angles to each other. These are three separate testing circuits. This arrangement covers a larger spread of angles from which monopoles may enter the detector than a single loop would. In addition, most trajectories will trigger two of the loops, and many will trigger all three. In this way coincidence counts will be provided that increase the statistical significance of the data.

Monopoles moving slowly near or through the earth are likely to pick up things, David Cline of the University of Wisconsin at Madison points out. Calculation shows that a monopole passing through the earth could pick up an atomic nucleus within about 10 kilometers of flight path, he says. If monopoles go slowly enough, they could pick up whole molecules, oxygen for instance, or "all kinds of garbage." They will never be bare, he says. If they are slow enough and pick up enough debris, they might get stopped. It would be worth looking for them in various places on earth. "Searches near the surface are not necessarily doomed," he says.

Ferromagnetic materials, such as iron ore, are particularly promising, Cline thinks, for trapping monopoles with velocities about one ten-millionth the velocity of light — that is, around 30 meters a second. With the Parker bound, he calculates, there should be no more than one monopole per ton of iron ore on the earth. The Cabrera event implies possibly more. At Black River Falls, Wis., is an ore crushing and pelletizing plant that processes 15 percent of the iron ore mined in the United States. Cline and collaborators are developing a detector rugged enough to work in the dirty environment of such a plant but sensitive enough to detect a monopole in the passing ore and also to distinguish it from a dipole, which might also be found in iron ore. "Have detector, will travel," he says.

Much deeper underground are various experiments looking for the radioactive decay of protons predicted by the GUTs. Some of the famous ones are in Utah, northern Minnesota, Baksan in the USSR and the Kolar gold fields in India. Some of these have seen events that might be proton decay. Now, according to Eugene Loh of the University of Utah, they are beginning to look particularly for the signature of proton decay catalyzed by GUMs.

Strange as GUMs are, there is even hope of using the more or less ordinary kind of particle-detecting materials common to physics laboratories. Barry C. Barish of California Institute Of Technology in Pasadena proposes acoustical detection of monopoles. He suggests that monopoles moving through a metal such as aluminum would cause a shock wave that would be detectable as an acoustical pulse in transducers attached to the edge of the metal. He is testing the idea with aluminum disks 144.5 centimeters in diameter. Given the Parker bound, one would need to cover a football field with aluminum to have a reasonable hope of success, he figures. At $500 per square meter one could cover 10,000 square meters (or something like two football fields) for $5 million, which is the cost of a typical high-energy-physics experiment, he says. His calculations show that silver would be a better detector than aluminum, but he didn't even bother to calculate the cost of paving a football field with silver.

Similar expanses of plastic detector left lying for a long time might come to show monopole tracks, suggests P. Buford Price of the University of California at Berkeley. Price also suggests searching for monopoles paleontologically by etching samples of ancient mica to look for tracks.

GUMs are much too heavy to be made in the accelerator and colliding-beam experiments typical of present-day particle physics, but they might interfere in characteristic ways with the processes that go on in accelerator experiments.

There is thus much scope for experimental ingenuity, and it is unlikely that these examples exhaust the means that can be thought up. The search is an exciting and necessary one. Monopoles have moved from the esoteric fringe of electromagnetism to the center of the grand unification of physics, and it seems they *must* be found. Investing so much importance in a particle that is so difficult to find and to prove found may turn out to be something of an intellectual embarrassment for the unifiers of physics. ☐

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