Particle Physics: Evidence for Magnetic Monopole Obtained

A visitor to a recent conference on the West Coast was asked, "Did you hear about the monopole?" Such was the way that news about potentially one of the most exciting and significant finds in experimental physics this century was being rapidly spread. The monopole, of course, is the magnetic monopole, a long-sought particle carrying a magnetic charge—in effect, a magnet with one pole. If the existence of the magnetic monopole can be confirmed, it would have profound implications for theoretical physics, and if monopoles could be captured, there could be experimental implications for high energy and particle physics as well. Technological applications for monopoles, however, are regarded as highly speculative, despite some rather dramatic scenarios recently.

A team consisting of P. Buford Price and Edward K. Shirk of the University of California at Berkeley, and W. Zack Osborne and Lawrence S. Pinsky of the University of Houston made the discovery this summer during analysis of the results of a cosmic ray experiment carried out on a balloon about 40,000 meters over Iowa nearly 2 years ago (*1*). A single track left in a detector array consisting of a Cerenkov fast film detector, nuclear emulsions, and sheets of Lexan plastic stacked together apparently was made by a magnetic monopole, according to the investigators. The monopole's magnetic charge was measured to be 137 times as strong as the electric charge of an electron and because the monopole passed cleanly through the detector stack, its mass was set at 200 times that of a proton or greater.

The discovery is sure to be subjected to the closest sort of scrutiny in the coming weeks and months. The surest verification of the find would be to actually trap a monopole—bring one back alive, as Price put it. Second best would be to find several more monopole tracks under similar experimental conditions. In the meantime, scientists want to be sure that there is no other possible explanation for the observed event. They also want to know why extensive previous searches for monopoles have not been successful.

The existence of magnetic monopoles would be warmly greeted by most physicists. Ever since James Clerk Maxwell provided a unified description of electricity and magnetism 110 years ago with his famous field equations, electric and magnetic phenomena have been seen as the consequence of the existence and motion of electric charge. The most modern and successful description of electromagnetic interactions, quantum electrodynamics, is also based on this assumption. Because of the apparent absence of magnetic charge, even the smallest magnetic entities, such as atoms with magnetic moments due to orbiting electrons and spinning electrons and nuclei, are dipoles. Continuous magnetic field lines stream from the north magnetic pole outside the particle to the south pole, and the net magnetic charge is zero.

Thus, Maxwell's equations are curiously unsymmetric. The existence of a magnetic charge with a magnetic field emanating radially outward and the concomitant possibility of a magnetic current would remove this unesthetic lack of symmetry between electricity and magnetism (Fig. 1). In 1931, the British theorist P. A. M. Dirac (who is now at Florida State University in Tallahassee) showed that the existence of magnetic monopoles was not precluded by quantum mechanics, thus eventually leading to a series (beginning about 1950) of experimental attempts to find monopoles, which has lasted up to the present. As each new particle accelerator has come on line, for example, one of the first experiments has been to try to create monopole pairs (one north and one south pole) by bombarding a suitable target with an energetic particle, each time without success. However, no accelerator present or planned could come close to producing a particle as massive as the reported monopole.

Dirac also showed that the existence of monopoles could explain the empirical fact that electric charge was quantized—an observation unexplained by any other theory of that time—by deriving the relation (in Gaussian units) $eg = n\hbar c/2$, where e is the electric charge of a particle, g is the magnetic charge of a monopole, n is an integer, $\hbar$ is Planck's constant divided by 2π, and c is the speed of light. Thus, the existence of even one pole of charge g would cause the quantum of electric charge to be $\hbar c/2g$. Conversely, using the empirically observed charge of an electron ($e^2 \approx \hbar c/137$) as the quantum of electric charge, Dirac predicted a monopole should have a magnetic charge which is an integer multiple of $68.5e$. The putative monopole with $g = 137e$ is thus in accordance with theory. Other properties of monopoles, such as mass, spin, or interactions with other particles do not fall out of Dirac's calculations.

$$\nabla \cdot \mathbf{E} = 4\pi\rho_e$$

$$\nabla \cdot \mathbf{H} = [4\pi\rho_m]$$

$$\nabla \times \mathbf{H} - \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} = \frac{4\pi}{c}\mathbf{J}_e$$

$$-\nabla \times \mathbf{E} - \frac{1}{c}\frac{\partial \mathbf{H}}{\partial t} = \left[\frac{4\pi}{c}\mathbf{J}_m\right]$$

Fig. 1. Maxwell's equations of electromagnetism in the notation of vector calculus and Gaussian units. **E** and **H** are the electric and magnetic fields; ρ_e and $\mathbf{J}_e$ refer to the density of electric charge and the electric current; ρ_m and $\mathbf{J}_m$ refer to the up-to-now hypothetical density of magnetic charge and the magnetic current. Without monopoles, the terms in brackets would be replaced by zeros, making Maxwell's equations unsymmetric.

To incorporate magnetic monopoles into quantum electrodynamics would not be a trivial task, according to Alfred S. Goldhaber of the State University of New York at Stony Brook, but neither would it spell the end of the theory. For example, the unparalleled agreement between measurements of certain quantities in atomic physics and the predictions of quantum electrodynamics would not be jeopardized, because any conceivable contribution that the monopoles could make to the calculated values of these quantities would be too small to be detectable, especially because of the large monopole mass.

The monopole might not have to be treated as a fundamental particle. In the last year and a half, there has been a revival of interest in classical field theories of the type known as non-Abelian gauge theories. The Dutch theorist G. 't Hooft provided the impetus for some of this interest when he showed that by combining electromagnetic and other fields in an appropriate way, so-called twists with all the properties of a monopole could be obtained, that is, the monopole drops out or is a consequence of the existence of the fields. A 't Hooftian monopole would be quite heavy, having a mass of 1000 protons or more. A twist can be crudely visualized by considering an infinitely long ribbon with a weight hanging on its "end." If the ribbon is twisted in one direction at some point on the ribbon and twisted in the other direction at another point on the ribbon, the twist and its antitwist will move toward one another and annihilate each other when they come together, like particles and antiparticles. The experimental discovery of very heavy magnetic monopoles might increase interest in these theories.

Price and his colleagues have pointed out that one consequence of their discovery, if it is confirmed, is that particles with fractional electric charges of $e/3$ or $2e/3$, such as the fabled quarks which are believed by many to be the building blocks

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from which the hadrons (particles that interact via the strong nuclear force) are built, cannot exist in a free state. This observation follows from the determination of the monopole charge as $137e$, so that only electric charges of $e/2$ or its multiples are allowed.

However, the possibility that free quarks may never exist does not mean their usefulness is at an end, say particle physicists. Sidney Drell of the Stanford Linear Accelerator Center, for example, noted that quarks have been very helpful as a classification scheme for hadrons so that, even as a fictitious mathematical construct, they would be too useful to let die. And Sheldon Glashow of Harvard University noted that, for many physicists, the real interest in quarks is in their predictive power, not in whether a free quark will ever be seen. Moreover, the inability to observe free quarks may mean that nature has put an end to the distressing possibility that there is an endless succession of smaller and smaller subnuclear particles to be uncovered at higher and higher energies.

Julian Schwinger of the University of California at Los Angeles has perhaps the highest hopes for monopoles. While all physicists seem to agree that learning how to fit monopoles into the current theories will increase scientists' understanding of the structure of matter, Schwinger would like to see a particular kind of monopole bring about a unified description of the strong nuclear and electromagnetic forces. For several years, he has been proposing that a particle he has called a dyon might be the fundamental building block of matter. A dyon has magnetic charge like a monopole but also fractional electric charges like quarks. (In Schwinger's theory, particles with fractional electronic charge would not be excluded by the existence of magnetic charged particles with $g = 137e$.) A proton, for example, could be constructed from dyons such that the net magnetic charge is zero and the electric charge is $+e$. Schwinger is hopeful that the discovery of a magnetic particle will increase interest in this approach.

As for practical applications of monopoles, scientists seem to regard them as highly speculative, although one physicist noted that in a civilization that is so profoundly based on electricity and magnetism, it would be surprising if monopoles could not be exploited. In the foreseeable future, assuming monopoles are caught and "brought back alive," the most plausible application seems to be as a projectile in an accelerator. In a back-of-the-envelope calculation, an accelerator the length of the 2-mile Stanford linear accelerator with 100 kilogauss magnets can be seen to accelerate a monopole to 6×10^5 Gev. For comparison, the accelerator at the Fermi National Accelerator Laboratory can boost protons to about 400 Gev.

The former energy would be just at the threshold needed to produce more monopoles, a prerequisite for their use in technological applications. Using another rule of thumb, to create a monopole with a mass of 500 proton masses (the mass value Price and his colleagues are settling for on the basis of refined calculations of the rate at which monopoles should lose energy in the detector), 10^6 Gev would be required.

Cosmic rays have long been thought to be the most fruitful place to search for monopoles. Monopoles created during the Big Bang at the beginning of the universe could have been accelerated by the weak magnetic fields that pervade the universe to energies of the order of 10^{20} Gev, and thus would be a component of high energy cosmic rays. Monopoles might also be created when other highly energetic cosmic rays collide with particles in the earth's atmosphere. However, attempts by various means to detect monopoles that would be trapped in magnetic iron ores on the earth's surface, in manganese and iron oxide sediments from beneath the Atlantic Ocean, in meteorites, and in moon rocks returned to the earth by Apollo astronauts have found no evidence for monopoles. Other searches not involving trapped monopoles have also been unsuccessful.

Ultraheavy Cosmic Ray Experiment

The balloon flight during which the monopole made its track was the last in a series of such flights designed by the Berkeley and Houston researchers to study ultraheavy cosmic rays (those with atomic numbers over 60). Although constituting only a minor component of the total cosmic ray flux, the rare, high Z cosmic rays can provide information about the synthesis of matter in exploding stars and about the source of cosmic rays. The experiment was designed in such a way that two never-observed types of particles of potentially great interest would also be detected if any were present: magnetic monopoles and superheavy nuclei with Z in the range from 110 to 114.

A detector package with an area of about 20 square meters was constructed by stacking together 32 Lexan plastic sheets (each about 250 micrometers in thickness), a nuclear emulsion 200 micrometers thick, a second emulsion used for certain tests, a Cerenkov radiator with a fast film to record any such radiation, and, capping the assembly, a top sheet of Lexan. The balloon-borne detector was launched in September 1973, and data were taken over a 60-hour period at a height of about 40,000 meters over Sioux City, Iowa.

Each of the components of the detector played a separate and complementary role. The Cerenkov radiator is a thin sheet of plastic (a dielectric). When a particle passes through the dielectric with a velocity exceeding the speed of light in the dielectric, Cerenkov radiation is given off. No Cerenkov image was observed at the point where the putative monopole was observed, thus setting an upper limit for its velocity of 0.68 the speed of light. Images were observed as expected where normal cosmic rays passed through the dielectric.

A charged particle passing through the nuclear emulsion leaves a track roughly describable as a bottle brush; that is, it has a dense core region and a less dense halo or bristle region. Estimates of the particle charge and velocity can be obtained by quantitative analysis of these regions.

The researchers at Houston spent about 2 years searching the 20 square meters of nuclear emulsion through a stereomicroscope with a field of view of about 6 millimeters. A total of 75 particle tracks were found. After locating the tracks, and making preliminary estimates of particle charge and velocity, Osborne and his associates sent this information to Berkeley, where analysis of the Lexan plastic detectors took place. The Houston group initially concluded that the particle causing the "monopole" track was a charged particle with a Z about equal to 80, and the particle velocity was put at about half the speed of light, in agreement with the null result of the Cerenkov detector.

As a charged particle passes through the plastic (Lexan is a commercial product used for such products as aircraft windows and motorcycle helmets), it ionizes nearby atoms and breaks polymer chains. This damaged area can be detected by etching the plastic in sodium hydroxide for periods of tens of hours. The etching causes cone-like pits in the plastic surface. The etch rate (length of cone divided by etch duration) can be quantitatively related to the ionization damage which in turn is related to the charge and velocity of the particle.

Price and his associates at Berkeley immediately noticed the peculiar "monopole" track, in part because a particle with a velocity of only $0.5c$ should have been readily stopped by the Lexan and should have caused increasing damage as it slowed down. Instead, the particle was not stopped, and the track indicated uniform damage. After further analysis, the Berkeley group concluded that either the track was caused by a superheavy nucleus with a Z of 125 or greater and a velocity of 0.92 the speed of light or by a monopole with a magnetic charge of $137e$ and an arbitrary velocity. More detailed analysis by Osborne and his associates showed that the track structure in the emulsion was consistent with the monopole explanation, but not with the superheavy nucleus.

While this evidence appears convincing, researchers will remain skeptical until more data and hopefully more monopoles are available. For example, implausible though it may seem, an electrically charged particle with a Z of about 70 and a mass of 10,000 protons could also have caused the observed track. Some physicists, including Owen Chamberlain of the University of California's Lawrence Berkeley Laboratory who has had a chance to examine the experimental results, believe that there is a small but nonnegligible chance that a less massive charged particle could have caused the observed detector response. If the particle suffered one or more collisions that caused it to lose some of its charge as it passed through the Lexan, the damage would approximate the uniform damage expected for a monopole.

Other scientists, such as Luis Alvarez of the Lawrence Berkeley Laboratory who was involved in the search for monopoles in the moon rocks, want to know why previous attempts to find monopoles failed. More than one unsuccessful monopole hunter suggested that monopoles with the charge, mass, and velocity reported by Price and his colleagues ought also to have been detected in their experiments. I' is important that this question have a satisfactory answer because the effective collecting power (measured in square meter-years) of the other experiments exceeds that of the balloon experiments by about a factor of 10^5. It is to be noted, however, that this large collecting power is based on the assumption of certain properties of monopoles that have not been verified.

The best answer would be to catch a monopole or at least obtain more monopole tracks. Price, Osborne, and their associates are looking into the possibility of an expanded balloon experiment embodying perhaps 50 balloons with 40 square meter detectors. Antarctica might be a good location for the search, they suggest, because the continuous sunshine in the summer there would enable balloons to be kept aloft for long periods.

Regardless of whether the present report of a magnetic monopole is confirmed by future experiments, it might be wise to recall what Dirac noted in his original paper: since the possibility of the existence of monopoles is not precluded by quantum mechanics, it would be surprising if nature did not make use of this possibility.

—ARTHUR L. ROBINSON

References

1. P. B. Price, E. K. Shirk, W. Z. Osborne, L. S. Pinsky, *Phys. Rev. Lett.*, in press.

LETTERS

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and even with colleagues at MIT to vague hints that an interesting structure had been observed in the electron pair spectrum. Some colleagues interpreted my remarks as important news, others did not. B. Richter (a member of the SLAC experimental team), who was in Cambridge to give the Loeb lectures at Harvard, did not seem particularly impressed by my story—told at a cocktail party at the end of October. I now regret having been so ambiguous in my remarks and I apologize to him and others for not being more explicit.

In any case, it became obvious that the news was spreading through the physics community. On 4 or 5 November, a technician working for a different MIT-LNS group at Fermilab remarked in a telephone call that the Ting group at Brookhaven was preparing a champagne party to celebrate their discovery of a new particle. I repeatedly urged members of the Ting group to end this state of "secret publication." The first news of the beautiful SPEAR experiments reached me on 10 November, when D. Frisch relayed the gist of a telephone call he had received from SLAC, and I, in turn, alerted Ting, who was on his way there.

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Island Sanctuary

The system of primary wildlife reserves which A. L. Sullivan and M. L. Shaffer examine in their article (4 July, p. 13) is an essential system for the ensuring of a diversity of plant and animal species in the future. They rightly point out the need for a hierarchy in developing such reserves.

I should like to offer a reserve, an established sanctuary, a coral atoll in the South Pacific which is already dedicated to scientific research. This atoll is 5 kilometers in diameter, 700 meters from outer reef to lagoon, and 5 meters above sea level. Two hundred years ago it served as the center of a Polynesian kingdom.

For those who wish to work in an island biogeography environment, the sanctuary provides a unique opportunity. Scientists interested in working on the atoll are cordially invited to respond. No grants are available, but the committee will help in other ways and housing will be provided.

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