Monopoles oughtn't to be a monopoly

Oddities in the single purported discovery of a magnetic monopole arouse experimental and theoretical controversy

BY DIETRICK E. THOMSEN

For 40 years magnetic monopoles were a curiosity of theoretical physics and a not very highly regarded curiosity at that. In the last five months they have developed into an experimental and theoretical controversy. Magnetic monopoles are objects that carry either a single north or a single south magnetic pole. They were introduced into theory to balance electric monopoles (positive and negative charges). In the practical world electric monopoles are frequently encountered, but all known magnets always had at least one north and one south pole.

Repeated searches for magnetic monopoles in nature all failed until the end of the summer of 1975. At that time a group of cosmic-ray observers from the University of California at Berkeley and the University of Houston claimed to have found the track of a monopole in their cosmic-ray detector (SN: 8/23-30/75, p. 118). The claim was immediately assailed on grounds of both experimental error and mistaken assumptions about the data (SN: 9/13/75, p. 104 and 10/4/75, p. 222).

The observers have been fighting back, but, at least temporarily, they have yielded a little ground. One of the leaders of the group, P. Buford Price of Berkeley, told the recent meeting of the American Physical Society that the group admits some errors of procedure, but they await further investigation of the data before concluding whether they were right or wrong. At the moment, says Price, they neither reiterate their claim to a monopole nor do they retract it, a nice ambiguous point on which to hang.

Meanwhile, theorists have conceived a new interest in monopoles. The theory that first postulated them is 40 years old and somewhat old-fashioned. The question is whether the newer theories admit monopoles and whether those monopoles have properties like those the experimenters have been looking for. The answer is that monopoles have a place in the newer theories, but when the predictions of the theories are compared with the observations of Price and colleagues (on the assumption that the observations are what they are purported to be), there are serious discrepancies between theory and experiment—at least according to the theorists.

The original theory of monopoles is due to P.A.M. Dirac, who, retired after a long career at Cambridge University in England, is now associated with Florida State University. The train of thought that led to magnetic monopoles began with the observation that electric charge is quantized. Electric charges are always integral multiples of the charge of the electron; no fractionation has ever been observed.

Yet the theory of electrodynamics as known 40 years ago gave no reason for this quantization. Theory was equally valid for electric charges in any amounts. A theory that does not account for all the observed facts is a deficient theory, and theorists worry about such things. Dirac discovered that if a magnetic monopole existed, it not only provided a philosophical balance between electricity and magnetism, it also put quantization of charge into the theory.

He found that he could derive an inverse proportional relationship between the strength of the basic electric charge and the basic magnetic charge. The constant of proportionality involved some of the basic units of quantum physics. So if both electric and magnetic monopoles existed, the quantization of both was apparent from this relationship, and it fitted the theory nicely. Since in principle only one magnetic monopole had to exist in the universe to make the relation true, Dirac was never terribly dismayed at the inability of experimenters to find them.

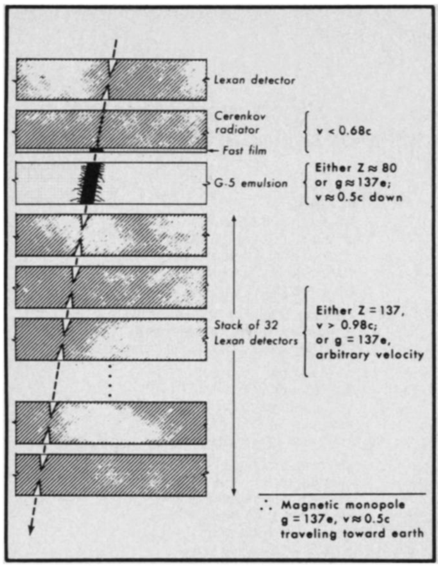
The theoretical formulations that Dirac used treated electromagnetism as something apart. The most recent formulations do not. They unite electromagnetism with another kind of force field, the weak interaction, which comes into play in certain activities of subatomic particles. The union is fruit of a very old yearning on the part of physicists to unite all the force fields they know in a single theoretical framework, and it is regarded by some as a first step toward the grand consummation. Effecting this much of a unified field theory required new mathematical methods and made a number of serious changes in the physical predictions of the theory (some of which seem now to be coming true). The question arises whether the new theory needs magnetic monopoles or even has room for them.

"Dirac's motivation is no longer so compelling," says Sidney A. Bludman of the University of Pennsylvania. Physics now knows many conserved quantized quantities so that the quantization of electric charge does not look as unique as it did 40 years ago. Quantization is commonplace and no longer seems to need explanation. Nevertheless, a prediction of a magnetic monopole can be derived from the unified formulation of the electromagnetism and the weak interaction. This was shown, Bludman says, by a Dutch theorist named 't Hooft, who contributed some of the seminal ideas that led to the unified theory. This modern monopole would be an extremely massive particle—6,000 billion electron-volts (6,000 GeV) or more than 6,000 times the mass of the proton, by one estimate. Its magnetic charge comes out the same as that of Dirac's monopole except for a factor of two. Dirac allowed half units of his proportionality constant and got a basic magnetic charge of 68.5 times the electron charge. In the recent formulation the basic figure is 137 times the electron charge.

Taking the predicted properties of monopoles and going on the assumption that in spite of other critics, "there is no reason not to believe the Price experiment," Bludman and Malvin A. Ruderman of Columbia University decided to compute the flux of monopoles that theory might expect and compare them with that seen in the detectors. They find, says Bludman, "an apparent contradiction between what experimentalists have seen and what theorists would expect."

Since the alleged monopole of Price and colleagues came in the cosmic rays, the theorists explored the possible methods of production and motion of monopoles in the space of the universe. The first point is that the monopole arriving in detectors at the upper edge of the earth's atmosphere has traveled across interstellar space. There are long-distance weak magnetic fields in interstellar space, and these should have accelerated the monopoles. Each monopole should extract 10^{11} GeV of energy from the field as it is accelerated. Now the field, which is one of the by-products of the rotation of the galaxy, has been around for 300 million years (approximately one galactic rotation period), and the passage of monopoles has not destroyed it by depleting its energy.

Therefore there must be very few monopoles around. There should in fact be no more than 10^{-16} monopoles per square centimeter of detector per second. Putting that in another way, if you fly one square centimeter of detector, you would wait on the average 10^{16} seconds (about 330 million years) for a monopole to hit it. But the one monopole claimed by Price and co-workers taken with the area of their



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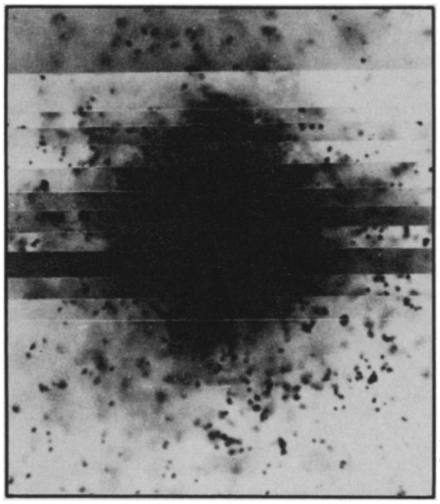
"Monopole" track that caused the fuss.



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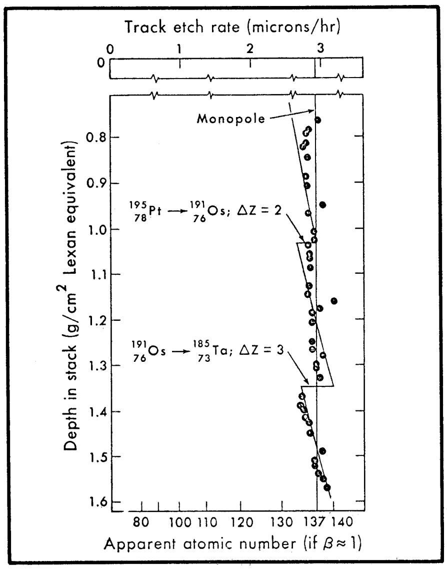
The track in the nuclear emulsion that determined the speed of the particle.

detectors and the flight time, yields a flux of at least 10^{-12} monopoles per square centimeter per second. That's 10,000 times as many, a very significant discrepancy even if it is based on only one sighting.

Another experiment, that of Luis W. Alvarez of Berkeley, which sought and did not find monopoles trapped by magnetic materials in samples of moon rocks, supports the theoretical limit of 10^{-16}

And there is yet another theoretical discrepancy. The experiment of Price and colleagues sees its monopole at fairly low energy—if the data are correct, it comes at about half the speed of light, fairly slow by modern particle-physics standards. Yet, if the monopole is an extremely massive body, as theory seems to expect, it must be produced at extremely high energy. Bludman says for a collision with a nucleon at rest something must come along with the fantastic energy of 10^{22} GeV (or 2×10^{19} times the most energetic products of accelerators on earth) to make a monopole.



Luis W. Alvarez

Alvarez's explanation of ionization data.

Thus monopoles are made at extremely high energy, but seen at low energy. This raises two serious connected problems. The energy to produce them, if it is as Bludman and Ruderman figure it, is unimaginable in processes in the present-day universe. Furthermore, there is not enough matter to slow them down sufficiently.

So Ruderman and Bludman go to the primordial universe, the early moments of the big bang, for their monopoles. Monopoles could have been made in the earliest microseconds of the bang when the temperature was 10^{24} degrees K. Then they could cool (that is, lose energy and speed) by the subsequent adiabatic expansion of the cosmos.

In spite of theoretical estimates of large mass, it is also possible to imagine low-mass monopoles (one might as well try everything to get theory and experiment together), provided they spent most of their lives trapped in dust grains. They would move through the universe with the dust grains. When the grain entered the atmosphere it would be ablated like a micrometeorite, leaving behind the low-mass (and low-energy) monopole to enter the detectors. But both of these outs, Bludman says, are hampered by flux limits that disagree strongly with the observation.

All that is assuming the observation is true. It has been severely attacked from an experimental point of view, and Price now gives some ground to the critics. One of the most serious objections was that the experimenters had mistaken the thickness of their Lexan plastic detectors and had incorrectly calibrated the Lexan. Price admits that this was so. The result is to lower the apparent magnetic charge of their particle from the 137 they first thought (which is consonant with theory) to an anomalous 115 or 120. They were saved from this discrepancy by graduate student Steve Ahlen, who calculated that their original assumption had been somewhat naive: A monopole that actually had a magnetic charge of 137 traveling at half the speed of light (as the other data seem to indicate) would affect the detector as if it had a charge of 115 or 120.

Another crucial point is that a magnetic charge would cause a constant amount of ionization throughout the stack of 33 Lexan sheets. At one point Alvarez dismissed 20 of the 58 data points on which the observers' belief in constant ionization is based. He also suggested that a heavy nucleus that fragmented twice could have fit the ionization data. Recalibration and remeasurement now give the observers 66 data points, and Price says they are confident "that the ionization rate is constant throughout the stack" and that the object was "not a twice-fragmenting nucleus." (Ionization by a twice-fragmenting nucleus would not be constant, but its changes would have a zig-zag pattern that could have fit some of the data points.)

At the moment the observers cannot completely rule out a uranium nucleus at high speed (0.8 that of light or more) or a curium nucleus. A curium nucleus at 0.86 the speed of light, Price says, could fit the Lexan data if one rules out the other detectors that were used to establish the speed of the object. (One expert in the use of photographic emulsions to track particles has said that you cannot use an emulsion to establish speed the way these observers did.) Nevertheless, there are 110 other tracks in the detector material that the observers have been studying for comparison, and if a uranium or curium nucleus made the disputed track it would have had the largest error margin of any track.

Price says as of now he is still sitting on the fence, but the data look very good. However, having made two acknowledged errors, the observers don't want to stick their necks out any further than that until more data analysis is completed.

Even if the data turn out to be correct, there remain the discrepancies with other experiments and theory. One can get out of them by finagling the properties of the monopole. "One can always think of properties of the monopole so that it will show up in one detector or another," says Price. The lack of monopoles in Alvarez's moon rocks can be explained by saying that if the monopole is as heavy as theory says, it goes right through the moon without being trapped. Alternately, a suggestion due to Dirac, the heavy monopole might decay into lighter ones (conserving the magnetic charge) so that it bounces around and is never trapped but bounces its way out.

Of course to do such things risks opening a whole new theoretical game with monopoles. That could lead to further uncertainties and diminish the hope (of at least those physicists who would like to believe in the existence of monopoles) that they can finally be pinned down. ☐