

search & discovery

Mixed reception for magnetic monopole announcement

The possibility that a fundamental magnetic charge might exist has intrigued physicists over the years. After the quantum theory of the magnetic monopole was developed in 1931 by P. A. M. Dirac, experimenters began looking for them. They have searched in cosmic rays, at particle accelerators, in iron ore, ocean sediment, meteorites and lunar rock.

Now a group of four cosmic-ray observers have announced finding an event that they interpret as being caused by a moving magnetic monopole. The team consists of P. Buford Price and Edward K. Shirk (University of California at Berkeley), W. Zack Osborne and Lawrence S. Pinsky (University of Houston). Their results appeared in the 25 August issue of *Phys. Rev. Letters*.

The Berkeley-Houston team says they have found a magnetic monopole of strength $g = 137 e$. (Dirac had predicted integral multiples of $68.5 e$.) It had a velocity of $0.5 c$ with error bars of $+0.1$ and $-0.05 c$. Their paper says its mass must exceed 200 proton masses. Since then further calculation puts a lower limit on the mass of about 600 proton masses.

The announcement made headlines in many newspapers and magazines

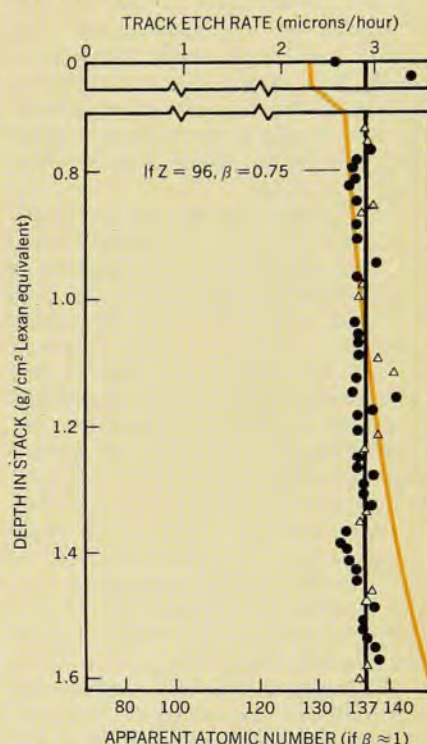
throughout the world and is being widely discussed in the physics community. Many observers were openly skeptical of the report, particularly since only one event was found. Some are arguing that the event could be interpreted instead as a high- Z nucleus.

The detector was flown in a balloon 130 000 feet above Sioux City, Iowa for 2.6 days beginning 18 September 1973 to look for heavy cosmic rays. It consisted (from top to bottom) of a Lexan detector, a Cerenkov detector, a G-5 nuclear emulsion and finally a stack of 32 Lexan detectors.

The routine followed was for the Houston group to scan the nuclear emulsion and then instruct the Berkeley group how best to process the Lexan sheets. During the nearly two years of scanning the Houston group found the unique event. By measuring the core and halo of the track, they estimated that if the cause were a charged particle, it had a Z of about 80 and a β of about $0.5 c$. From the distribution of delta rays, one can tell the particle was moving downward.

Then the Berkeley experimenters, guided by the estimates of charge and velocity, decided how long they would chemically etch the Lexan sheets. Etching essentially develops the track

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Etch-rate data from sheets of Lexan were used by the Berkeley-Houston experimenters, along with evidence from a Cerenkov detector and a nuclear emulsion, to conclude that they had observed a magnetic monopole.

SPEAR shows electron-muon pair produced unexpectedly

In a year full of surprises in high-energy physics, an experiment at the SPEAR colliding-electron-beam facility has uncovered yet another unexpected phenomenon: A significant number of events have been seen in which an electron and positron collide and produce one electron and one muon plus some missing energy. The experimenters can find no conventional explanation for this anomalous production of leptons and postulate that this reaction could proceed through the production of a pair of new particles. Each of the U particles, as they have been tentatively called, would then decay into an electron or a muon plus one or two neutrinos.

This work was done by a collaboration consisting of two groups from SLAC led by Martin Perl and Burton Richter and groups from the Lawrence

Berkeley Laboratory and the University of California headed by William Chinowsky, Gerson Goldhaber and George Trilling. Perl discussed the results at a Summer Institute on Particle Physics held at Stanford University in late July.

Although the data suggest the production of a pair of particles with strong leptonic decay modes, they cannot determine the exact nature of such particles. The most popular candidates are a heavy lepton, a heavy meson and an elementary boson. If the new particle is a heavy lepton l it might have the purely leptonic decay modes

$$l^- \rightarrow \mu^- + \bar{\nu}_\mu + \nu_l$$

or

$$l^- \rightarrow e^- + \bar{\nu}_e + \nu_l$$

and similar decay modes for the l^+ , where ν_l would be a new neutrino asso-

ciated with this heavy lepton. If the new particle were a heavy meson M , to explain the signal it must have relatively large leptonic decay modes such as

$$M^- \rightarrow e^- + \bar{\nu}_e$$

or

$$M^- \rightarrow \mu^- + \bar{\nu}_\mu$$

and similar decay modes for the M^+ . This heavy meson would be a candidate to have the property of charm, a characteristic of a fourth type of quark that has been postulated by some theorists. If the U particle were an elementary boson it should have similar decay modes but would be distinguished from the heavy meson by being a point particle, with no form factor associated with it. However the new particle is probably not massive enough to be the hypothetical intermediate vector boson that

would mediate weak interactions.

Experiment. This anomalous lepton production was seen as part of a study of electron-positron collisions at high energy—the same study that, together with an experiment by an MIT-Brookhaven team, produced the first evidence for two new particles at 3.1 and 3.7 GeV a year ago. Their apparatus consists of a cylindrical magnetic detector surrounding the beam axis. Inside the magnetic coil are cylindrical, magnetostrictive spark chambers and 48, 2.6-meter-long scintillation counters. Just outside are 24, 3.1-meter-long lead-plastic scintillator shower counters. Outside the 20-cm-thick iron magnetic-flux-return plates are magnetostrictive spark chambers referred to as the muon detection system.

The signature for an electron was a large pulse height in the shower counters. The requirements for a particle to be identified as a muon were that it be seen in at least one of the two muon chambers and that its pulse height in the shower counters be small. Any gamma rays seen in the shower counters were also noted. Within these muon-electron events, additional selection was made to reduce the contamination from pair production or from events where the muon or electron could be easily misidentified. This selection cut out events in which the muon and the electron were nearly coplanar and those in which the electron or muon has momentum less than 0.65 GeV/c.

The largest sample of data was taken at a center-of-mass energy of 4.8 GeV. At this energy the team found 24 muon-electron events that had no visible gamma rays. The SLAC-LBL team has tried to account for these events as hadrons that have been misidentified as leptons or as electrons that have been mistaken for muons and vice versa. However, these estimates fall far below the number of events actually seen.

The properties of these events are now being analyzed for clues to their origin. The plots of invariant mass and missing mass indicate that at least two particles are not detected. The momentum distribution predicts that, if the events are produced by the decay of a pair of particles, their mass lies between 1.6 and 2.0 GeV/c². The angular distributions are sensitive to whether the U particles decay into two or three bodies. Although the distinctions are not sharp, a two-body decay would most probably characterize a heavy meson or elementary boson, whereas a three-body decay mode is likely to signal a heavy lepton. Perl told us that the three-body decay fits the observed distribution but that the two-body decay fits only if the U particles have spin one and have some spin-spin correlations.

The observed cross section corrected only for background appears at 4 GeV,

risks to a maximum at 5 GeV and then falls off with energy. A $1/s$ behavior (where $s^{1/2}$ is the total energy) would be expected from the production of a pair of pointlike particles rather than from the heavy meson, which is expected to have a form factor. Thus, some theorists are leaning toward the heavy-lepton explanation for the U particle rather than the charmed-particle hypothesis. However, cautions Perl, the cross section should be corrected for losses caused by the momentum and angle cuts. These correction factors depend on the production and decay mechanism; they may be large and they certainly are energy dependent.

Other strange phenomena have recently been observed in weak interactions, but no one knows whether or not they are related. Specifically, high-energy neutrino-nucleon collisions studied at the Fermi National Accelerator Laboratory (NAL), have produced a number of events with two muons in the final state (PHYSICS TODAY, March 1975, page 24). Members of the Harvard-Penn-Wisconsin-NAL collaboration that have studied these events feel they provide strong evidence for production of a hadron with a new quantum number. Other experiments have observed direct production of leptons in proton-proton interactions at a higher rate than was expected (PHYSICS TODAY, October 1974, page 18).

Other evidence for a heavy lepton was postulated earlier this year to explain four or five events that had been seen in neutrino interactions studied in the Kolar Gold Mines, India by a collaboration from the Tata Institute of Fundamental Research, India and the Osaka City University, Japan.¹ In these events, which constitute about 25% of the neutrino interactions seen within the rock wall of the mine, the experimenters measured several charged tracks, which they interpret as coming from the decay of a new neutral particle produced in the neutrino interaction. However, an NAL experiment, headed by Frank Nezrick and Byron Roe, to study neutrino interactions in the 15-foot hydrogen bubble chamber, reported no indications of the above effect. In another NAL experiment the Harvard-Penn-Wisconsin-NAL group looked for long-lived penetrating neutral particles produced by neutrinos. One member of this group, Alfred Mann (University of Pennsylvania), cautioned that comparison is difficult because the accelerator experiments are not really identical with the cosmic-ray ones. Still, his collaboration does not see an effect comparable in magnitude to that of the Indian-Japanese experiment.

Meanwhile, several more experiments are being planned to study the muon-electron channel with better muon de-

tectors or with better hadron-lepton separation and also to look for other decay modes or other anomalous effects from this possible new particle. —BGL

Reference

1. M. R. Krishnaswamy, M. G. K. Menon, V. S. Narasimham, N. Ito, S. Kawakami, S. Miyake, Phys. Lett. **57B**, 105 (1975).

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left by a particle, which shows up as a cone. From the etch rate (microns per hour), one can determine the ratio of Z to β . In the figure, data are shown for both 20- and 30-hour etches. The experimenters say that the best fit to their data is given by a zero slope (rate of change of etch rate with depth). For the maximum slope consistent with the data the charge is about 125 and β about 0.92. Subsequent measurements, still in progress, indicate a Z/β about 121. A calculation by Steven Ahlen (Berkeley), using previously published estimates of ionization by monopoles, indicates that this value of Z/β is consistent with that expected for a monopole with $\beta = 0.5 c$.

The colored curve, obtained with the original uncalibrated estimate, shows the best fit to the data for a nucleus of $Z = 96$; its velocity would be about 0.75 c . A similar curve with Z about 78 and β about 0.68 c would fit the scale of Z/β as revised. If one assumes that the event is caused by a magnetic monopole of strength g , one instead obtains the black line in the figure. It is consistent with a monopole of strength twice that calculated by Dirac; his minimum value was $hc/2e = (137/2)e$. The monopole could have any velocity sufficient to penetrate the 1.6-g/cm² stack, the experimenters say. Arguing that the emulsion data do not allow the particle to have such a high velocity, the experimenters say that therefore the particle must be a monopole.

There is an additional restraint on the velocity of the particle. The fast-film Cerenkov detector does not show an elliptical Cerenkov image; such an image would indicate that the particle was moving at a velocity greater than or equal to 0.68 c . So the experimenters believe that the particle velocity was less than 0.68 c .

A further argument in favor of the monopole hypothesis, the Berkeley-Houston group says, is that the particle ionized heavily and at a constant rate, a property predicted by Dirac. They state that a particle with only electric charge and velocity 0.5 c would have to be more massive than 10^4 proton masses to fit the data.

In their paper, the group says that in order to penetrate the Lexan stack the monopole must have had a mass greater