Search for Magnetic Monopole in Deep-Sea Sediment

BY HENRY H. KOLM

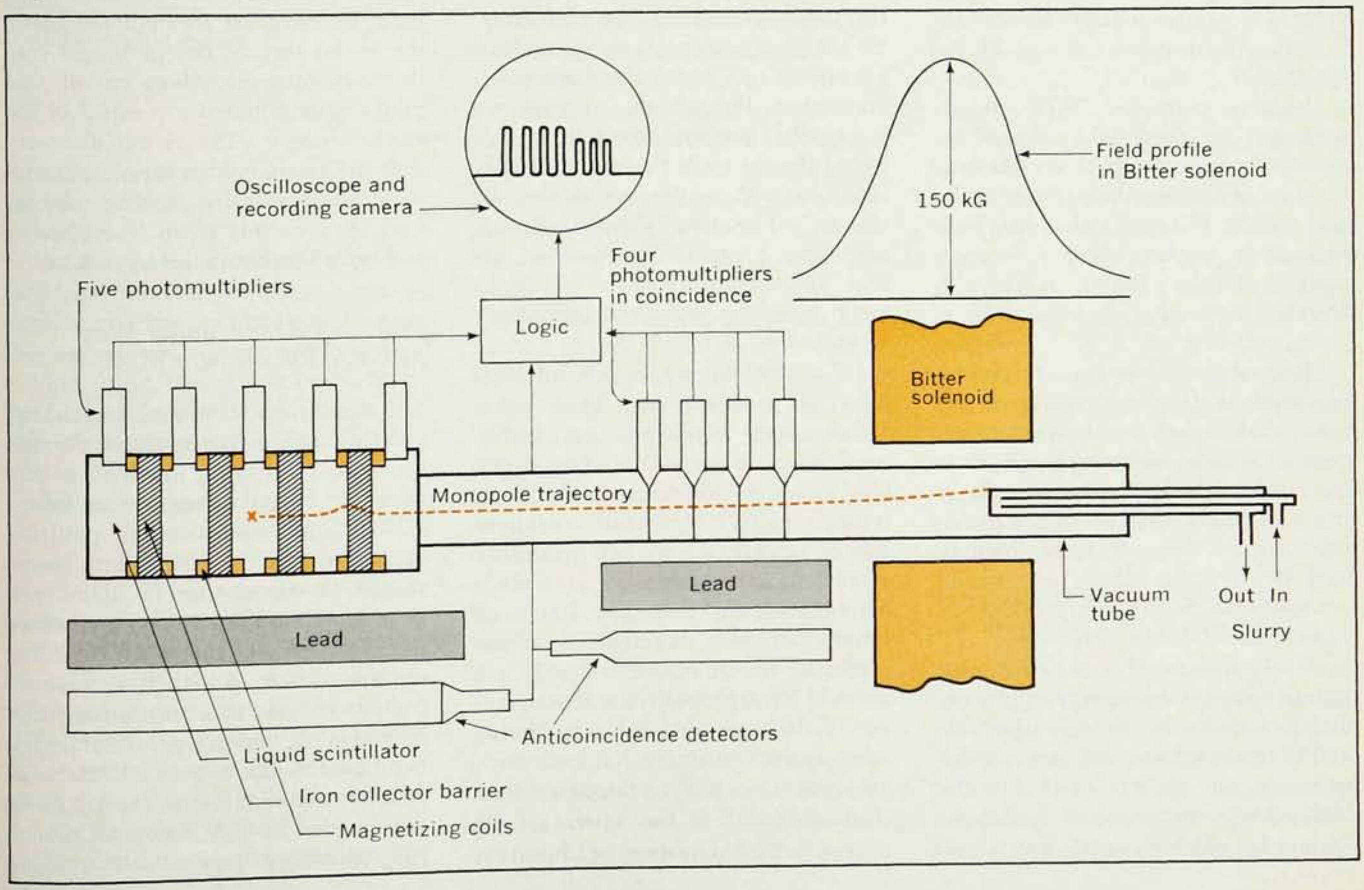
Magnetic fields in the 150-kG range are being used at the MIT National Magnet Laboratory in an attempt to extract magnetic monopoles from ferromagnetic materials, where they may have been accumulating for geological periods of time. Although results are inconclusive so far, they are compatible with a charge one third the value predicted by P.A.M. Dirac in 1931.

If monopoles were found they might, for example, explain the high-energy component of cosmic radiation as well as extensive air showers; they might account for some of the properties of quasistellar objects ("quasars"); they might even be implicated in reversals of the earth's magnetic field.

The MIT search promises to be the most thorough ever conducted for the elementary particle, which has evaded observation since its existence was predicted by Dirac at about the time he predicted the positron. A particle of magnetic charge quantized in units of $\hbar c/2e$, Dirac pointed out, would not only be compatible with quantum field theory, but is in fact required to explain the quantization of electric charge. Reconsidering the problem from a somewhat different viewpoint, Julian Schwinger deduced in 1966 that the monopole ought to have twice the charge predicted by Dirac. That no monopoles have been found does not reflect any lack of interest or effort but simply suggests that they may be too massive to have been produced in man-made radiation and too rare to have been found in cosmic radiation.

Synchrotron experiments, all with negative results, were done at Berkeley, CERN and Brookhaven, and the Brookhaven experiment (directed by Edward Purcell of Harvard), which used 30-GeV protons could have pro-

MONOPOLE DETECTOR extracts monopoles from deep-sea slurry and accelerates them to 100 GeV. Monopole (trajectory in red) is focused toward magnetic axis. After passing through four thin scintillators monopole enters liquid scintillator that is divided into five cells by four iron barriers (collector targets). Monopole trapped in collector can be reextracted by putting collector in place of slurry tubes.



duced monopoles less massive than 2.9 GeV. A cosmic-ray search was made in 1951 by Willem Malkus, who used a solenoid to funnel field lines, and thus monopoles, through nuclear track emulsion; he would have detected one north monopole per cm^2 in 300 years. In 1966, W. C. Carithers, R. Stefanski and Robert Adair, repeating the experiment with a much more powerful Brookhaven bubble-chamber magnet, would have detected one north monopole per cm^2 in 10^6 years. This upper limit may sound very impressive but not if one remembers that meteorites, which are not considered particularly rare, arrive at the rate of one per cm^2 in 10^{16} years.

Ferromagnetic materials. In 1958 Eiichi Goto of Tokyo University pointed out that monopoles would be trapped in ferromagnetic material. Goto, Kenneth Ford and I, collaborating in 1962 at the National Magnet Laboratory, calculated this macroscopic interaction and found that Dirac monopoles would be extracted from magnetite by a 17-kG field and from iron by a 53-kG field. These values are only slightly higher for Schwinger monopoles (18 and 57, respectively).

Using a portable 170-kG pulsed magnet, Goto, Ford and I searched for monopoles to a depth of several centimeters in a magnetite outcrop in the Adirondack Mountains that has been exposed to cosmic radiation since recession of the glacier. We also searched meteoritic material with a continuous magnet.

However monopoles that escaped recombination after their creation in the primordial fireball are destined to acquire ever increasing energies in their travel through the universe. It is therefore likely that prevalent monopoles are too energetic to be thermalized by the atmosphere and would penetrate too deeply to accumulate in surface material or in meteorites.

Goto and Luis Alvarez of Berkeley estimate the present energy of primordial monopoles to be about 10^{20} eV and suggest that they may account for extensive air showers and for the high-energy component of cosmic radiation for which no satisfactory accelerating mechanism has yet been devised.

Ocean sediment. Energetic monopoles would be thermalized by a sufficient depth of ocean water and would then follow the earth's field lines to the bottom so as to accumulate in magnetic components of sediment. Deep-sea sediment thus appears to be the most promising terrestrial source of monopoles, even though 8 km of ocean would stop only monopoles less energetic than 10^{16} eV.

Therefore I have been searching deep-sea sediment (dredged from 2–3-km depths by the Scripps Institution) with the collaboration of Robert Filz and the late Hermann Yagoda. This search has turned up several emulsion tracks that are geometrically compatible with south monopoles, and, strangely, exhibit constant ionization to their termination; unfortunately, however, they are not nearly as heavy as the track of a Dirac monopole should be.

To eliminate the ambiguity of emulsion technique based on speculative track characteristics, Francesco Villa and Allen Odian (SLAC) and I are converting the MIT experiment to a statistical basis by the use of scintillation detectors in a suitable logic array. By trapping monopoles in an iron target system (see figure) and reaccelerating them through the magnet, we can provide positive detection regardless of the nature of the monopole's interaction with matter, or indeed, its charge. The new experiment, improved with Atomic Energy Commission sponsorship, is now ready to begin searching significant quantities of sediment.

In a preliminary search of 800 liters of sediment, we have again found effects similar to our earlier emulsion tracks. Our confidence level has now become so high that it compels us to give serious consideration to a possibility we had previously dismissed: the possibility of a magnetic monopole that has a charge lower than the minimum quantum predicted by Dirac. The energy acquired by a monopole in a given magnetic field is proportional to its charge whereas the rate at which it loses energy (ionizes) in passing through matter is proportional to the square of its charge. The ionization produced in our scintillators is compatible with monopoles that have one third of Dirac's charge. Such monopoles would easily have passed through our target.

Our new apparatus is designed to investigate this new hypothesis that seems absurd within the framework of Dirac's reasoning and twice as absurd from the viewpoint of Schwinger. However, it appears to be the only hypothesis capable of explaining all of our observations as well as the negative results of all those who have looked for the monopole before us.

Once trapped, a monopole would provide a very useful projectile for high-energy experiments. It could be reëxtracted and accelerated repeatedly to energies several orders of magnitude greater than synchrotron energies now envisaged, and this could be done with only a simple, inexpensive magnet system.

Reversals of the earth's magnetic field, as evidenced by paleomagnetic studies, might be related to monopole showers. An incidence rate of one per cm^2 per second would have canceled the earth's field in one month. Although such a monopole accumulation would eventually have been neutralized by diffusion through the earth, the initial surface charge would constitute a magnetic short circuit that might have initiated a reversal of the earth dynamo. The recent discovery that the latest field reversal coincides with an extensive tektite shower suggests a cosmic event is implicated and lends support to this hypothesis.

Colliding Beams under Way At CEA, Planned for SLAC

The Cambridge Electron Accelerator, a 6-GeV alternating-gradient electron synchrotron, is being modified to produce and store counter-rotating beams of 3–3.5-GeV electrons and positrons in the synchrotron itself. Both beams should be circulating in about two years. At Stanford University, where the first experiments with colliding electron beams of 330 MeV were reported one year ago, an experiment at 550 MeV is under way. Stanford is hoping to build a 3–4-GeV electron-positron colliding-beam facility to be fed by the 20-GeV linac. Although the Weisskopf high-energy advisory