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ABSTRACT

The quoted flux in a recent report of a detected magnetic monopole is inconsistent by factors on the order of five hundred thousand with ocean-bottom searches. One resolution of this incongruity is that monopoles are trapped somewhere between the top of the atmosphere and the ocean bottom. We have searched for monopoles in the atmosphere and ocean water and have found none at levels substantially below the numbers expected if the monopoles were trapped.

Recently, Price et al.[1] (hereafter designated PSOP) have reported evidence for the detection of a magnetic monopole. They interpret their data as a monopole with a mass greater than 200 proton masses. Magnetic monopoles with masses in this range have been suggested by Carrigan[2] and in a unified gauge theory advanced recently by 't Hooft.[3] PSOP report that the magnetic charge is roughly twice the charge of the Dirac monopole. The particle apparently did not stop in the lexan-emulsion stack and hence was not recovered. PSOP argue that since no monopoles have been reported in all previous emulsion-lexan balloon and satellite flights that the flux should be quoted for the entire set of exposures. This corresponds[4] to an area-time factor of 3 m^2-years or 10^{12} cm^2 sec. The PSOP experiment is not inconsistent with monopole limits established at accelerators such as searches carried on at Fermilab[5] and the ISR[6] since the mass is much larger than that which could be produced at these installations.

Several previous experiments have set magnetic monopole production upper limits for area-time factors of the order of 5×10^{17} cm^2 sec. Most of these searches have been at ground level or below. Among these experiments, the ones with the largest area-time factors are searches of the ocean bottom by Fleischer, Price, and others,[7] Kolm et al.,[8] and a search of lunar material by Eberhard et al.[9]

An incongruity exists since the area-time factor limits set in the previous experiments are more stringent than that determined by PSOP by a factor on the order of five hundred thousand. There are at least three possible explanations for this situation: 1) The PSOP experiment is incorrect.

Alvarez,[10] Fowler,[11] and Friedlander[12] have explored this possibility and discussed several problems associated with the experiment. Independently, Fowler and Alvarez suggest the event was due to a platinum nucleus which underwent spallation interactions in the stack. 2) The properties of magnetic monopoles are not correctly understood. PSOP advance this interpretation to explain the incongruous situation. 3) The monopoles are misplaced some-where in the expected passage from the upper atmosphere to ground level or the sea bed. Misplaced is used here in the sense that the monopoles might not be in the places they were expected to appear. The present experiment has been carried out to examine this hypothesis.

Conventional wisdom holds that a magnetic monopole in a fluid will drift along a magnetic field line until it attaches to a fixed binding center such as a nucleus or a ferromagnetic or paramagnetic material. Such a center might be the deep sea ferromanganese crust searched by Fleischer, Price, and others.[7] Few monopole searches have been conducted in fluids because of this expected behavior. The most sensitive fluid search was the experiment of Carithers et al.[13] where flux lines in air were gathered by a powerful dipole magnet. This experiment had an area-time factor seventy times larger than PSOP but had a magnetic charge cutoff somewhere between two and three Dirac charges.

The arguments concerning monopole behavior in fluids seem to be fundamentally sound. However, in view of the incongruity we are faced with, this hypothesis should be reconsidered. An example of how the fluid argu-ment might break down is for a monopole to bind tightly to something in the air or water on its passage from the upper atmosphere so that it would not attach to the sea-bed binding centers. This might happen if the monopole was bound in a large cluster of material such as oxygen and could not get close enough to a ferromagnetic center to attach itself or if the cluster acted as a balloon which bouyed the monopole.

For the area-time factor determined by PSOP, recombination of monopole, anti-monopole pairs may be non-negligible. The density of magnetic poles in a fluid with the assumption of a uniform distribution is given by

$$\eta = \frac{\tau}{Ah}, \tag{1}$$

where A is the area-time factor determined for the mechanism that is populating the fluid, h is the height of the fluid, and τ is the lifetime for recombination. Strictly speaking, τ is the lifetime of the pole in the fluid due to any loss mechanisms such as recombination, loss to binding centers, or loss out the top of the atmosphere. If the lifetime for loss out the bottom (and the top) of the fluid volume is short, then monopoles should appear at the ocean floor. Since they don't, this loss mechanism must be negligible if the PSOP result is correct. τ should be replaced by the age of the fluid if the lifetime for recombination is substantially larger than the fluid age.

As an approximation, the recombination rate per monopole is given by

$$R = \pi b^2 v \eta = \frac{1}{\tau}, \tag{2}$$

where v is the effective pole drift velocity and b is the separation distance at which two oppositely charged magnetic poles will just recombine. For plausible drift velocities ($\sim 2\times10^4$ cm/sec), b values predicated on nuclear sizes ($\sim 10^{-7}$ cm) and an area-time factor based on PSOP, τ is about one million years and η is equal to approximately 0.06 monopoles/liter for ocean water and 0.05 monopoles/liter for air. Note that τ is inversely proportional to the density of monopoles in Eq. (2) so if the expected monopole density decreases because the monopole flux decreases (that is the area-time factor increases), the lifetime for recombination will increase.

This experiment to search for monopoles in sea water and air used the high magnetic field extraction and ionization range detection method employed for our Fermilab search.[4] The extraction apparatus consisted of a 50 cm long, 80 kilogauss superconducting solenoid with a 4.76 cm diameter warm bore. Downstream of the solenoid was a series of very thin scintillation counters (0.25 mm thick) to determine monopole ionization loss. These were calibrated with alpha sources and light pulsers. Interspersed with the counters were iron and aluminum range absorbers. These absorbers were constructed in such a way that they could be fitted into the bore of the solenoid if necessary, and any stopped monopole recycled through the apparatus. The detector system was under vacuum so that a monopole could not stop in air and be lost for recycling. Air and sea water were introduced into and removed from the bore of the solenoid on the side opposite the detectors. The fluids traveled along the solenoid axis to the 72 kilogauss position through a 1.9 cm diameter copper pipe and then were returned through the same side via a concentric pipe. The fluid pumps were placed on the exit line to avoid pump contact with any magnetic monopoles in the fluids. The fluid system was separated from the vacuum by a 0.05 mm copper window.

The experiment consisted of accelerating any monopole from the fluid through the solenoid and searching for the expected very high ionization loss of the monopole in the scintillation counters. Any monopole accelerated in the apparatus should come to rest in the absorber system. The basic trigger consisted of the first three counters firing in coincidence. The magnitudes of the energy deposits in the scintillation counters were photographed to record the event and determine the magnetic charge. Special efforts were made to preserve the linearity in the region of magnetic charge reported by PSOP. The timing resolution of the counters was made broad (40 nanoseconds) to accommodate the low velocity expected for a monopole with a very high mass as suggested by PSOP.

The upper limit for the mass range of the detector is set by the focal properties of the solenoid and the timing of the counters. With a 1.9 cm diameter fluid transfer pipe, a magnetic charge as small as 1/6 of a Dirac charge with a mass as large as 1250 GeV would be detected with 100% efficiency. Higher values of the magnetic charge could go to equivalently higher masses. For example, a monopole with twice the Dirac charge and a mass up to 15,000 GeV would be detected with 100% efficiency. The apparatus was tuned to accept charges from 1/6 of a Dirac charge to 24 Dirac charges. The lower limit was determined by the smallest energy deposit detected in the trigger counters. The expected range of a monopole with 24 times the Dirac charge was just sufficient to penetrate the first 3 counters. This determined the upper charge limit.

In the course of the fluid runs, each magnet polarity was run for half the time.

The air for the experiment was taken at Fermilab. The air was removed directly from the atmosphere through a pipe large enough so that most air molecules would not strike the walls of the pipe. Sea water was scooped from the Atlantic Ocean six miles from Long Island where the water depth was 30 meters. The water was shipped to Fermilab in 55 gallon drums lined either with 0.09 or 0.18 mm of polyethylene. Water remained in the drums for about thirty days before it was processed. Sea water was used since fresh water has a shorter effective lifetime. Note that for both the water and air, the mixing in the fluids is sufficient to preclude any advantage in taking samples from some special place, for example, preferring polar to equatorial fluids because of the existence of higher magnetic fluxes at the poles. The ocean mixing time is less than ten thousand years[14] and the stratosphere to troposphere mixing is no more than decades. We processed 68.4×10^3 liters of air and 1630 liters of sea water.

No monopole signal was detected in the water or air sample. Based on this, the 95% confidence limit on the density for magnetic monopoles is less than one magnetic monopole per 22,800 liters of air and less than one monopole per 540 liters of sea water in the mass and charge range examined by the apparatus. Note that these upper limits on the monopole densities do not depend on the recombination rate.

It is possible to construct lifetimes and area-time factors for the monopoles in the fluids if a model for recombination is used. For our simple model [Eq. (2)], the lifetime for recombination in air is 1.4×10^9 years and for water is 34.2×10^6 years. With these lifetimes, the equivalent area-time factors are then $1.2\times10^{18}\ cm^2$ sec for air and $1.2\times10^{15}\ cm^2$ sec for water. These area-time factors are substantially larger than the area-time factor deduced from PSOP. This indicates that the monopoles are not lost in the sea or atmosphere unless elements of the recombination model are in serious error; that is, the recombination rate is somewhat higher than indicated by the lifetimes given above.

In view of these limits, if the PSOP observation is correct, the monopole that was observed must have had unexpected properties.

If PSOP is correct, there will be a finite recombination rate in the fluid leading to monopole, anti-monopole annihilation. Monopole annihilation for PSOP magnetic monopoles should lead to a unique signature--the release of several hundred GeV of elementary particles and gamma rays from an annihilation at rest in the laboratory system. The area-time factor deduced from PSOP can be used to calculate an annihilation rate per unit volume. This rate is independent of the monopole–anti-monopole lifetime for annihilation provided that the lifetime is short compared to the age of the particular fluid. For these assumptions, there will be about one annihilation per day in a volume of air 200 m on a side. An annihilation rate this small appears to be difficult to detect in a straightforward way.

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