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EXPERIMENTAL SEARCHES FOR MAGNETIC MONOPOLES*

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ABSTRACT

Analysis of the sensitivity of previous negative searches for magnetic monopoles shows that they constitute prior evidence against the monopole interpretation of the event reported as "evidence for detection of a moving magnetic monopole". The strength of the evidence varies with the unknown mass of the monopole. For $M \leq 10^5$ GeV, odds are greater than 10^6 : 1 against. For larger masses, the limits depend strongly on assumptions about the range of monopoles and the threshold for detection of monopole tracks in obsidian. In no case are the odds, less than 8 : 1 and they may be no less than 8000 : 1 against. Since the reported event may also be due to an electrically charged heavy particle, it is probably not due to a monopole.

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I. INTRODUCTION

This afternoon we will review the sensitivity and assumptions of the most sensitive monopole searches[1-5] published prior to the report of "Evidence for Detection of a Moving Magnetic Monopole."[6] None of them detected a monopole. It is appropriate to consider this prior evidence when judging the monopole interpretation of the event in question since the searches reviewed are those that would be most capable of detecting monopoles with properties similar to those deduced from the reported evidence.

II. PROPERTIES OF THE REPORTED MONOPOLE

Figure 1 taken from ref. 1 is a schematic representation of the stack of detectors in which the monopole candidate was detected. The evidence, taken at face value as published, indicates that <u>if</u> the particle responsible for the emulsion track and Lexan etching carried a magnetic charge, then the magnitude of its charge would be 137e, or 2 times the minimum charged allowed in Dirac's theory,[7] its velocity would be $\beta = 0.5^{+.1}_{-.05}$ and its mass would be greater than 200 m_p. Furthermore, its large mass implies that it could not have been produced in the atmosphere and slowed to $\beta = 0.5$,[8] and, therefore, must have been a component of the primary cosmic rays. The searches reviewed were sensitive to a flux of this type of monopole.

III. SENSITIVITY OF PREVIOUS SEARCHES FOR MONOPOLES IN COSMIC RAYS.

The reported event was taken from a set of exposures in balloon flights and one satellite exposure which had a combined event collecting power of 3 m^2 - yr. Assuming a solid angle factor of π steradians, the one event corresponds to a measured flux of 3.4×10^{-13} cm^{-2} sec^{-1} sr^{-1}. Using this flux as an estimate of monopole flux in the cosmic rays we predict for those previous searches that detected no monopoles the number they should have seen. This is a means of indicating their sensitivity, the larger the number predicted, the more sensitive the experiment. The results are shown as a function of the kinetic energy of the incident monopole in Fig. 2.

The sensitivity of the various experiments depend on the unknown range of monopoles of a given energy. We parameterized the range in terms of an effective charge N,[3] such that, if the only energy loss was due to ionization, the effective charge would be equal to the actual charge, ν, in units of the minimum charge allowed in the Dirac theory.[7] Of course, we expect that other energy loss mechanisms such as nuclear interactions or bremsstrahlung will be present so that $N \geq \nu$. The range R, in g/cm^2, of a monopole of kinetic energy E is then given by $R = E\ (\mathrm{GeV})\ /\ 8N^2$. To show the variability of the sensitivity of the experiments in case energy loss processes other than ionization are taken into account, the predictions have been evaluated for both $N = 2$ and $N = 20$. The curves on Fig. 2 are drawn dotted for $N = 2$ and dashed for $N = 20$. Where dashed and dotted curves overlap they are shown as solid lines.

It is clear from Fig. 2 that the previous experiments ABCD,[1-4] taken at face value rule out the possibility that the reported event was due to a particle to which they were sensitive. We must consider the assumptions and any limitations of these experiments.

IV. CRITIQUE OF PREVIOUS SEARCHES

We classify the previous experiments in categories.

1. Positive signature experiments, in which the presence of a single monopole in the sample would be detected. Experiments of this type are listed in Table I, they are experiments A, B and C of Fig. 2.

2. Negative signature experiments, in which it can be determined with certainty that no monopole has traversed a sample by the absence of a

signature due to a highly ionizing particle. If these experiments had seen a signal, there is in general no way to distinguish between a signal due to an electrically charged particle and a magnetically charged partical without further assumptions. Experiments of this type are listed in Table II, they are experiments D and E of Fig. 2.

3. Indirect evidence based on the predicted effect a flux of monopoles would have on other experimental observations in the universe. Evidence of this type is listed in Table III[9,10] and one result is shown as F on Fig. 2.

In the tables we have indicated the limitations of each of the experiments for the detection of $\nu = 2$ monopoles.

The positive signature experiments depend on the accumulation of monopoles in a sample over long periods of time. Monopole accumulation in the lunar sample depends on a) the slowing down and thermalization of monopoles, guaranteed by their intense electromagnetic interaction with matter, and b) their being trapped in materials containing ferromagnetic components. They will either be trapped in the ordinary matter or, if not, then their trapping by ferromagnetic components is ensured by energy conservation.[11] No solid arguments have been advanced to throw doubt on these two assumptions. For the experiments using terrestrial samples, there is the additional assumption that the monopoles thermalized in the atmosphere or ocean will migrate along the earth's magnetic field lines to the ocean bottom before being trapped. This also seems a reasonable hypothesis, though maybe less certain than the previous two.

The monopoles would have been detected in the lunar samples by the current change they induced in a closed superconducting solenoid when they were passed through the solenoid.[12] This method does not alter the sample in any respect and the measurement can be repeated at will. Furthermore, the sensitivity of the detector to magnetic charge can be established without magnetic charge because of the identical roles played by current of magnetic charge and magnetic induction changes in the Maxwell equation

$$\vec{\nabla} \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t} - \frac{4\pi}{c}\vec{J}_m$$

For the terrestrial samples of references 4 and 5, the detection of monopoles was to be accomplished by extracting them from the sample and accelerating them to high energy using a large magnetic field. The monopoles would then be detected by their large ionization. The necessity of extracting them and accelerating them to the detectors puts a limit on the monopole mass for which this technique would work. That limit is $M \lesssim 2 \times 10^4$ GeV.

From the positive signature experiments A, B and C on Fig. 2 alone, we conclude that for monopole kinetic energies less than 10^6 GeV and hence masses $< 10^6$ GeV for non relativistic monopoles like the event of ref. 6, the odds are greater than 1000 : 1 against the event of ref. 6 being a monopole.

For larger monopole energies and masses, the negative signature experiments give the most restrictive limits. The obsidian sample of ref. 4 should have detected about 8,000 tracks of the type reported in ref. 6. The authors indicate that calibration of obsidian threshold for identification of high charge should allow the detection of $\nu = 2$ monopoles. However, we understand that the threshold value has been questioned on the basis of new unpublished calculations of monopole energy loss that would lead to damage in crystals.[13] If this challenge can be substantiated, the only remaining experimental limit from negative signature experiments would come from ref. 5. Here the detection is with Lexan, the same detecting material used in ref. 6. The odds in this case are only 8 to 1 against the event of ref. 6 being a monopole.

In addition to the positive and negative signature experiment results, there is indirect evidence against such a large flux of monopoles from an argument in ref. 10 regarding the collapse of the galactic magnetic field. A flux of monopoles would cause the fields to decay with a time constant inversely proportional to the number density. By equating the decay time constant to the estimated time constant of generation of the fields ($\sim 10^8$ years), and assuming a velocity $\beta \approx 1$, the "sensitivity" limit shown as F on Fig. 2 was deduced. The meaning of this limit is as follows. If the true monopole flux in interstellar space was 7,000 times less than that implied by the one event of ref. 6, then the galactic magnetic fields would decay as fast as they were generated. Hence, this argument indicates odds of 7000 : 1 against the event being a monopole.

V. CONCLUSION

The results of previous monopole searches for a flux of monopoles in the cosmic rays have been reviewed in the light of the reported monopole candidate.[6] The results depend on the assumed mass and range of the monopole candidate. Assuming a range energy relationship based on N = 2 (dotted and solid curves of Fig. 2) and assuming the mass is of the same order of magnitude as or smaller than its kinetic energy (as was the case for the monopole candidate) we draw the following conclusions:

1. $M < 2 \times 10^4$. There are three independent experiments[1-3] that give odds $> 10^6$: 1 against the monopole interpretation.

2. $2 \times 10^4 < M < 10^6$ GeV. The Lunar experiment[3] gives odds greater than 1000 : 1 against the monopole interpretation.

3. $M > 10^6$. The absence of tracks in obsidian[4] gives odds of 8000 : 1 against the monopole hypothesis.

4. Any M. The existence of galactic magnetic fields gives odds of ~ 7000 : 1 against the monopole hypothesis.[10]

Taking these published experiments before the reported event at face value, there are a priori odds greater than 8000 : 1 against the event reported in ref. 6 being due to a magnetic monopole.

If the threshold for detection of $\nu = 2$ monopoles in the obsidian of ref. 4 can be effectively challenged and some way is found to either generate galactic magnetic fields faster or to keep monopoles from destroying these fields, the a priori odds can be reduced to as low as 8 : 1 against the candidate for monopole energies and masses $> 10^7$ GeV.

Finally, the event was detected using a technique suited for a negative signature experiment. There is nothing in the experiment that demands that the track be due to a magnetically charged particle. The event could as well have been due to an electrically charged particle of high enough mass and may yet be explained in terms of a known high Z nucleus.[14] We conclude that the event is most probably not due to a magnetic monopole.

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TABLE I

POSITIVE SIGNATURE EXPERIMENTS

Material Searched	Depth of Sample (g/cm^2)	Method of Detection	Limitations for Detecting $\nu=2$ Monopoles	Ref.
Manganese Nodules	$\sim 2.7 \times 10^5$	Extraction + Solid State Track Detectors	$M < \sim 2 \times 10^4$ GeV	1
Deep Sea Sediments	$\sim 4.4 \times 10^5$	Extraction + Scintillator or Emulsion	$M < \sim 2 \times 10^4$ GeV	2
Magnetic Extract from Georgia Clay Deposit	$\sim 2.5 \times 10^4$	Extraction + Scintillator or Emulsion	$M < \sim 2 \times 10^4$ GeV	2
Lunar Soil and Rocks	10^3	Measure Magnetic Charge by Induction in a Coil	None	3

TABLE II

NEGATIVE SIGNATURE EXPERIMENTS

Material Searched	Depth of Sample (g/cm^2)	Limitations for Detecting $\nu=2$ Monopoles	Ref.
Mica	$\sim 2.0 \times 10^6$	Threshold for Detection only certain for $\nu \geq 3$	4
Obsidian	$\sim 10^4$	Some loss of Solid Angle for $\nu=2$ (Threshold for $\nu=2$ has been questioned by one of the authors.[13])	4
Lexan	$\sim 10^3$	Same material as used in ref. 1	5

TABLE III

INDIRECT EVIDENCE

Phenomenon Examined	Limitations for Detecting $\nu=2$ Monopoles	Ref.
Low Rate of Muon Poor Extensive Air Showers and Inverse Compton Scattering of 3°K Black Body Radiation on Monopoles	$M \leq 2\times10^4$ GeV. Beyond this Mass the Flux Limits are Less Restrictive than those of Other Experiments	9
Decay of the Galactic Magnetic Field	No Limitation is Discussed in ref. 10.	10

FIGURES

Figure 1. Schematic of a stack of balloon borne detectors in which an event was detected and reported as evidence for a magnetic monopole. Figure taken from ref. 6.

Figure 2. Predictions of the number of monopoles that would have been detected in previous monopole searches A, B, C, D, and E if the true flux of monopoles was 3.4×10^{-13} cm^{-2} sec^{-1} sr^{-1}. A, ref. 3.; B, ref. 2.; C, ref. 1.; D, ref. 4.; E, ref. 5.; F, ref. 10., see text for the significance of this "prediction"; G. ref. 6.

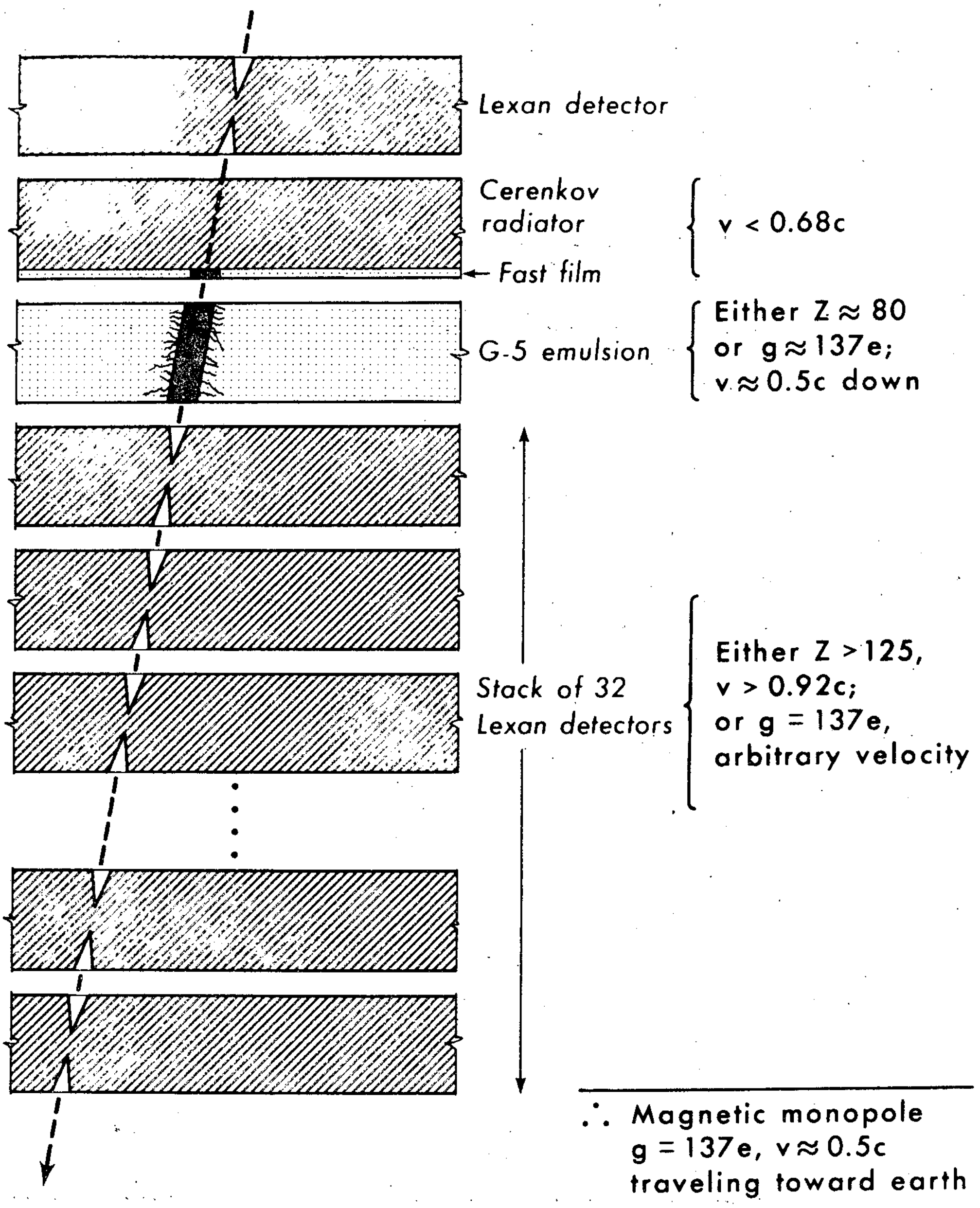

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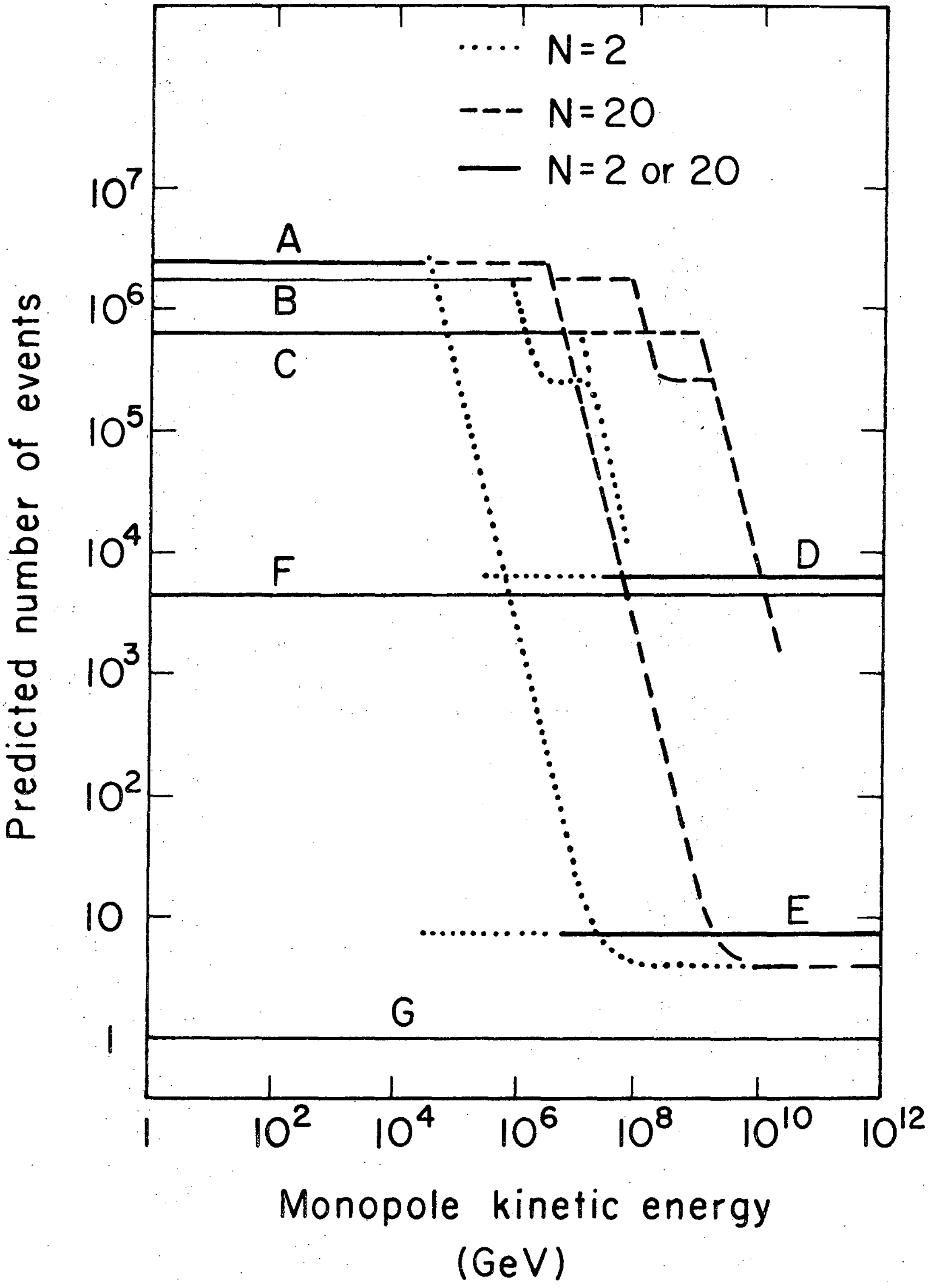
Fig. 1



XBL 762-2255

Fig. 2