AN EXPERIMENT TO DETECT GUT MONOPOLES

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1. INTRODUCTION

Recent advances in the development of Grand Unification Theories have led to several interesting predictions. One of these states that Grand Unification Monopoles (GUMs) exist as solutions in many non-abelian gauge theories. Another consequence of Unification is the possibility of baryon decay. In fact it has been postulated[1,2] that GUMs may catalyse proton decay in a reaction of the type

$$p + m \longrightarrow m + e^+ + mesons$$
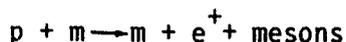
Although it is still unclear with what cross section this interaction would proceed, it has been suggested that it would be comparable to that of a strong interaction ($\sigma \sim 10^{-26}$ cm^2). If this is indeed so then the detection of magnetic monopoles may be feasible by observing successive proton decays.

Another experimental technique used to detect monopoles depends on the possible ionization loss by GUMs in their passage through ordinary matter. Although the processes involved in such interactions are well understood for relativistic particles, the exact mechanism by which GUMs of various velocities might lose energy is still uncertain.

For velocities in the range $10^{-4} < \beta < 10^{-3}$ (where β = v/c), energy losses are mainly due to adiabatic excitation of the atoms, arising from the interaction of atomic electrons with the monopoles magnetic field. The monopole leaves the atoms in an excited state, an effect known as the Drell[3] effect. This may be detected by observation of the de-excitation photons or by observing ionization caused by energy transfer from excited atoms to complex molecules with small ionization potentials.

The Drell mechanism is effective when the monopole-atom collision energy exceeds the spacing of atomic levels. However, for smaller values of β, energy loss is due to elastic monopole-atom collisions arising from the long range magnetic charge - magnetic dipole interaction. The energy is eventually dissipated into heat.

Detailed estimates of the stopping power and scintillation light yield for the passage of a GUM through NE110 plastic scintillator have been made by Ahlen et al.[5] They have shown that while there is an effective velocity threshold for observable energy loss by a GUM in this material of $\beta \sim 6 \times 10^{-4}$, for values of $\beta \geqslant 7 \times 10^{-4}$ a considerable enhancement in energy loss is expected as compared to that of a relativistic muon.

Based on these predictions of how a monopole would interact with matter, a detection system has been constructed, in which monopole catalysis of baryon decay may be observed while simultaneously monitoring ionization loss of slowly moving particles.

OUTLINE OF EXPERIMENT

The main component of the experimental system is a cylindrical tank containing .88 tons of water. The passage of relativistic charged particles through this tank will be marked by the production of Cerenkov radiation. It has been suggested that a monopole passing through a tank such as this would catalyse successive baryon decays, thus giving a unique signature in a detector of this type, observable through the ensuing decay products. The aim of the experiment therefore is to monitor the water for a number of events which are statistically unlikely to have arisen from the cosmic ray background.

The number of 'Rubakov' type decays that might occur during the passage of a monopole through the water tank can be estimated using the formula for the interaction length given by

$$\lambda = \frac{4300 \, \beta}{\sigma_0 \rho} \quad \text{(cm)}$$

where σ_0 is the interaction cross section of the order of unity for strong interactions and ρ is the density of the medium in which the interaction takes place.

The path length will be uncertain by several orders of magnitude because of the considerable uncertainly in σ_0. However, for monopoles with $10^{-5} \ll \beta \leqslant 10^{-3}$, λ could be in the range between .4 mm and 40 m. Thus for a detector such as ours, where the average track length is of the order of 1 metre, the passage of GUMs, with values of σ_0 and β that combine to give values of λ in excess of .25 m, is unlikely to be registered.

In addition to this 'Rubakov' type experiment, one which detects an ionization loss by a slowly moving particle has also been incorporated into the system. Based on the assumption that a detectable signal would be observed when a GUM encounters a scintillation counter, six plastic scintillators have been placed around the water detector in an attempt to register the passage, through the water, of a slowly moving ionizing particle.

In this set up an event would be deemed to have occurred when an ionization loss is observed in any two of the six scintillators accompanied by at least one interaction in the water tank.

The resolving time between successive scintillator pulses will determine the range of β for which the experiment is sensitive. For $10^{-5} \leqslant \beta \leqslant 10^{-3}$ a resolving time of 1 ms should be suitable. By excluding pulses occurring within a few micro seconds of one another, events due to the cosmic ray background can be considerably reduced.

3. DESCRIPTION OF EXPERIMENTAL SYSTEM

The water tank (diameter = .92 m, height = 1.35 m) is viewed from above and below the water by 2 RCA 4525 photomultiplier tubes. The signals from these tubes are fed directly to individual Le Croy MVL100 amplifier-discriminators. Logic level outputs from these amplifiers are fed to a pair of pre-set counters, which generate a master trigger pulse when the number of applied output pulses exceeds a previously stored value in either a 400 ns or a 2 μs interval. Having selected pre-set values of 3 events in 400 ns and 4 in 2 μs, the expected

accidental rates from the cosmic ray background are 2.5×10^{-4} d^{-1} and 3.7×10^{-7} d^{-1} respectively.

The analog outputs from the MVL100s are fed to a Transient Data Analyser (TDA), which samples and digitizes the waveform every 50 ns. The resultant 8 bit words are stored in 4096 bytes of memory. Upon receipt of a master trigger pulse, further sampling is disabled and the contents of the memory are transferred to a VAX11/780 for subsequent analysis.

The six plastic scintillators, surrounding the water, are each viewed by 2 RCA 4518 photomultiplier tubes, which are then coupled to six individual MVL100 amplifiers. These are followed by several Le Croy modules, which are used for the purposes of level transformation and coincidence forming. The resultant logic levels are then applied to some additional circuitry which generates a master trigger pulse if signals from any two scintillators occur, separated in time by an interval of between 10 μs and 1 ms.

At the same time a second TDA samples the analog outputs from the water tank every 1 μs and stores the resultant 8 bit words in 1024 bytes of memory. This gives a total sweep time of 1.024 ms. When a master trigger pulse is generated, the contents of the TDA memory are 'frozen' and transferred to an on-line micro-computer, where they are examined, in real time, to determine whether or not any observable interactions occurred in the water detector. A positive conclusion to this examination results in a further interrogation of some associated latches in order to determine in which scintillators the interactions occurred and the length of the interval that separated them in time.

Both this information and the contents of the TDA memory are recorded and the system is then re-armed, ready for the next event. If however no interactions were observed in the water tank then the system is re-armed immediately, thereby reducing the dead time considerably.

4. RESULTS

The efficiency of the water tank detector in registering a 'Rubakov' type decay will vary with both the interaction length and the GUM's velocity, expressed in terms of β. The efficiency decreases at large values of β ($> 10^{-2}$) because of the limited resolving time of the detector (~50 ns). At lower values of β the time between interactions is such that the criterion of 4 events in 2 μs can no longer be satisfied.
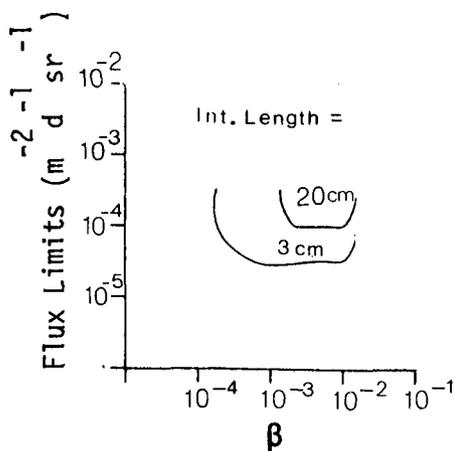

Fig. 1 plots the estimated flux as a function of β for 2 different interaction length, both within the sensitive range of the detector.

The 'Rubakov' experiment has now been in operation for almost 2 years with an estimated live time of 80%. During this time no candidate events have been observed leading to an estimated upper limit on the flux of

$$7.82 \times 10^{-5} \ m^{-2} \ d^{-1} \ sr^{-1}$$

The ionization loss detection system has only recently come on line and as yet no results are available from this experiment.

5.   REFERENCES

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