Search for Dirac magnetic monopoles
Experiment E7

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1. From January to April 1961 two types of experiments have been performed at CERN with emulsions on Dirac monopoles.

In type I, a target of approximately 3 gr/cm^2 thickness was inserted into the circulating beam of the proton-synchrotron where monopoles formed by proton-nucleon collision, or by secondary gamma rays, would lose energy rapidly by ionization and would come to rest in the target. The target was then removed from the PS and placed in a pulsed field of 60 to 150 kilooersted, which should be sufficient to remove tightly bound monopoles from the target. Several different target materials and arrangements of pulsed field, were used for this type of experiment.

In the type II experiment a magnetic field of several hundred oersted was applied to the target in the accelerator each beam pulse. Monopoles pulled out of the target by this magnetic field would be accelerated up a vacuum pipe through a thin exit window, and would produce distinctive tracks in nuclear emulsions placed above the exit window.

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Immediately after the bombardment, the target was removed, and exposed to the pulsed magnetic field of type I experiment, to detect monopoles if they were bound too tightly to be removed by the field that was applied in the PS.

All these experiments have given values for the upper limit of the cross-section for production of pairs of monopoles in proton-nucleon collisions which are between a few units in 10^{-40} cm^2 and a few units in 10^{-39} cm^2, values similar to the latter have been obtained also by the groups of Collins, Purcell et al. at Brookhaven, and Giacomelli et al. at CERN, both working with counters.

2. In both type I and type II experiments there are a few assumptions about certain properties of the Dirac monopoles such as their chemical binding in molecules, diffusion through crystals, extraction work from para- or dia-magnetic materials etc, which considerably reduce the strength of the conclusions derived.

For this reason, since November 1960 (Memorandum SC/13227/Int/1275 by Hoffmann and Vanderhaeghe) exposure time has been required at the PS for a type III experiment in which all monopole properties deriving from their interaction with matter do not enter in an essential way in the interpretation of the results.

In type III experiments the poles, created in a target placed in the internal proton beam are deviated by the magnetic field produced by a pulsed coil placed nearby the tank (Krienen coils).

Their kinetic energy is large enough to come out of the tank (araldite) and enter a long solenoid (Giacomelli and Rome solenoids) which brings them into a stack of emulsions placed at a distance of a few meters from the machine.

During all their path from the target to the meulsions, the kinetic energy of the monopoles remain always very large so that all chemical or solid state effects cannot be of any importance.

The time for such an exposure was already assigned and the experiment had to be made, during the first two weeks of July. On the occasion of a seminar on Dirac poles held at CERN the 20th April, some theoretical objection was raised which appeared to indicate that the existence of poles would contradict well established laws such as Lorentz invariance. We have, therefore, renounced to do the exposure in order to wait to clarify the theoretical situation about monopoles.

Since then the problem of Dirac poles has been examined carefully with the conclusion that no objection of this type can be made to Dirac formulation of the problem although the argument in favour of the existence of poles is very weak, as one should say, everybody knew before.

The main conclusions reached on the occasion of a discussion held at CERN on 7th June are given in the appendix together with a few clarifying comments.

3. Under these circumstances we believe that it is worthwhile to complete the series of experiments with emulsions on Dirac poles as they had been originally planned and therefore we ask for the time at the PS for an experiment of type III. All the necessary equipment exists and can be set up in a short time. A program for computation of the trajectories is ready and will be used for a detailed computation of the efficiency of collection of the poles.

Appendix A

Summary of points made at the discussion on Dirac poles, held at CERN 7.6.1961

1. A classical theory in which besides electric charges also magnetic charges act as sources of the electromagnetic field can be developed to its end without any serious difficulty. Such a theory has many appealing features, arising from the high symmetry of the Maxwell equations.

2. Classically the static field produced by a point pole g and a point charge e has an angular momentum around the line joining g to e equal to

$$(1) \qquad \frac{eg}{c} ,$$

i.e. a value independent from the distance of the two points. The quantity (1) enters in a suggestive way also in the description of the motion of a point charge in the field of a point pole at rest or vice versa of a point pole in the field of a point charge at rest. The Dirac relationship

$$(2) \qquad \frac{eg}{c} = \frac{1}{2} n\hbar \qquad n = 0, \pm 1, \pm 2$$

fixes the value of the quantity (1) in terms of $\hbar$.

3. Because of the Dirac relation (2), the very appealing symmetry mentioned under 1, is destroyed: electric charges are weakly coupled ($e^2/\hbar c = 1/137$), magnetic charges are strongly coupled ($g^2/\hbar c = 137/4$) to the e.m. field. A convenient asymmetry in the values of the masses could, in certain cases, reduce the effect of the asymmetry of the values of the charges. The Dirac theory is made by introducing into the wave equation a vector

potential which is singular along a line joining the pole to infinity (string). This potential actually corresponds to a solenoid infinitely long with infinitesimal cross-section: the magnetic flux 4φ coming out of the pole is actually brought to the pole through this solenoid from infinity. The relationship (2) comes out by imposing the single valuedness of φ when the string goes around a point charge, or vice versa the point charge goes around the string.

4. The Dirac theory (first quantization) when properly developed - i.e. by introducing the canonical variables describing the motion of the string - does not contradict any general law; in particular does not contradict relativity and causality.

5. However, the Dirac theory is not at all complete and one does not know how to do the second quantization of the e.m. field in presence of charges and poles. Obviously, the main disturbing feature, specific of poles, is represented by the string which in its turn is due to the use of potentials. On one hand, the usual present quantum theory involves the representation of the electromagnetic field by means of potentials; on the other hand, the concept of magnetic pole is foreign to the idea of a vector potential which can survive only by becoming singular.

A few of the many questions waiting for answer :

1) Is it possible to develop a theory in which "Dirac strings" are avoided ?

2) If yes, does in such a theory still exist a relationship of the type of Eq.(2) which fixes the values of g in terms of e, $\hbar$ and c ?

Took part in the discussion:
Bell, Feld, Fierz, Glaser, Jauch, Lee and van Hove
Also present:
Amaldi, Gatto, Vanderhaeghe and Ferrari

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These notes, put down by E. Amaldi immediately after the discussion have been fully approved by Feld, Lee and Van Hove.

The following comments have been sent by others:

Bell thinks that the summary is fair and notices that if the answer to question 1) is "yes", then so also should be the answer to question 2).

Fierz almost agrees but stresses the point that there is no properly developed theory of the so-called charged poles. He thinks that point 4 is rather a pious hope than a fact. He thinks, may be in contrast to Lee, that in a properly developed theory the strings attached to the poles do not drop out and so each pole together with its strings is already a system of infinite degree of freedom. He does not see how poles may be built into modern quantum mechanics. To question 2) he also gives a positive answer.

Jauch notices that the symmetry due to the existence of poles (point 1) is spoiled also by the fact that the magnetic four-current is a pseudo-vector, while the electric four-current is an axial vector. He points out that a theory of the electromagnetic field in which the fields are used instead of the potentials has been formulated by Novobatski, Belinfante and Valatin.