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NEW APPROACHES FOR SEARCHING FOR THE DIRAC MAGNETIC MONOPOLE

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Новые подходы к поиску магнитного монополя Дирака

Предлагаются не применявшиеся ранее три подхода к поиску монополя Дирака — объекта, существование которого было предложено П. Дираком более 80 лет назад для объяснения квантования электрического заряда.

Первый способ использует ускорение монополя магнитным полем, причем это ускорение постоянно, если магнитное поле однородно и постоянно. Измеряя время прохождения объекта через эквидистантные регистрирующие плоскости, можно сделать заключение о характере его движения.

Второй способ предполагает восстанавливать траекторию движения в однородном и постоянном электрическом поле, которая только для магнитного монополя должна представлять собою окружность или ее часть.

Третий способ основан на постоянстве потерь энергии монополем Дирака на ионизацию в многослойных пассивных диэлектрических трековых детекторах, помещенных в постоянное электрическое поле.

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New Approaches for Searching for the Dirac Magnetic Monopole

Three new approaches, not applied earlier, are proposed to search for the Dirac monopole — an object whose existence was proposed by P. Dirac more than 80 years ago to explain the electrical charge quantization.

The first approach assumes that the monopole must be accelerated by a magnetic field, and such acceleration is constant in the magnetic field which is homogeneous and constant. The conclusion about the object movement nature can be drawn by measuring the time marks for equidistant registering planes.

The second approach is supposed to reconstruct the movement trajectory in the homogeneous and permanent electrical field, which is the circle or its part for the magnetic monopole.

The third approach is based on the constancy of energy losses by Dirac monopole due to medium ionization in the multilayer passive dielectric tracking detectors placed in the homogeneous and permanent electrical field.

The investigation has been performed at the Veksler and Baldin Laboratory of High Energy Physics, JINR.

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In 1931, P. A. M. Dirac published the paper entitled «Quantized singularities in the electromagnetic field» [1]. That paper offered the theory which restored the symmetry between electricity and magnetism and allowed the existence of isolated magnetic poles, whose charge must be quantized.

The quantized magnetic charge g_m is related to the electric charge e by the expression, which includes the universal constants $\hbar$ (the Planck constant) and c (the speed of light in vacuum)

$$g_m e = \frac{1}{2}\hbar c n,$$

where $n = \pm 1, \pm 2, \ldots$. From this relation, it follows that a value of monopole magnetic charge is $g_m = 68.5ne$. The theory contains no predictions about the mass of a monopole. If one suggests the equality of the classical radii of a monopole and an electron $r_0 = e^2/(m_e \cdot c^2) = g_m^2/(M_m \cdot c^2)$, where m_e is the mass of electron, then the Dirac monopole mass $M_m = 2.4$ GeV. The symmetry of the Maxwell equations gives an opportunity to assume that the monopole moving in the electromagnetic field is influenced by the action of the Lorentz force:

$$\mathbf{F} = g_m \mathbf{H} + g_m/c\,[\mathbf{V} \times \mathbf{E}],$$

where $\mathbf{H}$ is a vector of the magnetic field intensity, $\mathbf{V}$ is a vector of a monopole velocity, and $\mathbf{E}$ is a vector of the electric field intensity. Let a monopole with charge g_m moves in constant and homogeneous magnetic field $\mathbf{H}$ along the field lines. After passing distance $\mathbf{L}$, its energy increases by

$$\Delta T = g_m(\mathbf{H}\,\mathbf{L}).$$

So the energy increment of a monopole with a unit charge in the field of 1 kGs on the 1-cm distance will be equal to 20.55 MeV [2].

The majority of experiments aimed at searching for the Dirac monopole was based upon the assumption of its high ionization capability. The specific ionization of a medium by a relativistic monopole with a unit magnetic charge would be about 8 GeV/(g/cm^2); the energy losses of monopole in materials used in experimental physics such as aluminum, iron, copper, lead, and tungsten would range, respectively, from 20 GeV/cm up to 120 GeV/cm [2].

As for the technique of searching for the Dirac monopole, the experiments on accelerators can be divided into 4 groups. The biggest number of studies has been performed using nuclear tracking detectors, where strongly ionizing objects produce damages, which allows the tracks of particles to be reconstructed after the etching procedure using a microscope. In the comparable number of experiments, scintillation counters have been used. Only a few experiments applied nuclear photoemulsions or induction coils.

The general outcome of the searches was the restrictions on the monopole masses and on the production cross sections in the reactions with various interacting particles and at various energies [3].

We propose to experimentally establish the presence or absence of the characteristics of the movement, which are inherent exclusively to the objects carrying the Dirac magnetic charge:

a) the acceleration of the monopole in the magnetic field along magnetic force lines;

b) the movement trajectory of the monopole in the electrostatic field has to be a circle (or its part) in the plane perpendicular to the field strength vector;

c) the constancy of medium ionization by the Dirac monopole [2].

The discovery of any of those characteristics will indicate that the Dirac monopole exists.

Consider these suggestions one by one.

In case a), let us discuss the following scheme of the experiment. Three thin parallel registering planes positioned at the same distance from each other supply the time marks when a particle is crossing the given counter. Let us put this structure in constant and homogeneous magnetic field H directed perpendicularly to the registering planes. Let the magnetic monopole with charge g_m and mass M_m move along the magnetic force lines with a constant acceleration $a = g_m H/M_m$. Measuring the crossing times of the registering planes (t_i, $i = 1, 2, 3$), knowing the distances between those planes, and supposing that the monopole moves with constant acceleration, we can calculate the value of acceleration by using the kinematic formulae. Let us take the time resolution to be 100 ps for counting planes. Then, already for the 3-m distance (the time of flight of about 10 ns), one can reliably establish the fact of the acceleration of the Dirac monopole in the moderate magnetic field of 3–5 T for the range of monopole masses up to 1 TeV and for a wide range of velocities.

The issue of the background load of the apparatus must be studied by the Monte Carlo method. Electrically charged particles produced at the same interaction as monopoles (or produced under different interactions, but passing through the apparatus together with the monopole), may be an accidental mimic of the monopole trajectory. However, we believe that the reconstruction of particle trajectories in a set-up with excellent space resolution together with the measurement of the time instants when the object crosses the counting planes, will completely remove the problem of background.

In case b), the trajectory of the monopole in a homogeneous electrostatic field must be a circle (or its part) in the plane, which is perpendicular to the field intensity vector. Let us estimate the needed electrostatic field for the trajectory radius $R = 1$ m. The calculations have shown that, for a monopole with minimal magnetic charge and mass $M = 3$ GeV, the electrostatic field intensity must be equal to $E = 4.4 \cdot 10^5$ V/m for the velocity $V = 0.01c$ and to $E = 4.4 \cdot 10^6$ V/m for $V = 0.1c$. The choice of detectors for the set-up to realize the idea of using a homogeneous electrostatic field requires an additional consideration. The size of a set-up, as is seen from the presented estimation, is quite feasible.

Case c) can be realized by means of thin (about 100 μm thick) foils of mylar, lexan, and cellulose nitrate, which can be assembled as a multilayer cylindrical structure with of about 2 cm thickness along the radius. Inside a hollow cylinder a target can be positioned or two counter beams collide. This detector, being put into the homogeneous electrostatic field, will allow one to determine not only the characteristic features of ionization losses along the object trajectory, but also the curvature radius of a trajectory for a relatively slow ($V \leqslant 0.01c$) magnetic charge. The handling of the irradiated detectors is going within the standard etching scheme of nuclear tracking detectors. Applying the electrostatic field gives a new quality to the search experiments based on the supposed constancy of the ionization of media by the Dirac monopole.

It may be said for sure that every accelerator in the world included the experiments to search for the Dirac monopole. We intend to prepare the proposal of a specific experiment based on the above-presented properties of moving magnetic objects in a magnetic or electrical field or in a solid. The experiment can be carried out at the accelerator complex of heavy ions Nuclotron–NIKA of LHEP, JINR (Dubna) and/or at LHC of CERN, as well.

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REFERENCES

1. *Dirac P. A. M.* // Proc. Roy. Soc. A. 1931. V. 133. P. 60.
2. *Barkov L. M., Gurevich I. I., Zolotarev M. S., Makar'ina L. A., Martem'yanov V. P.* // Zh. Eksp. Teor. Fiz. 1971. V. 61. P. 1721.
3. *Nakamura K. et al. (Particle Data Group)* // J. Phys. G, Nucl. Part. Phys. 2010. V. 37. P. 075021.

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