USSR ACADEMY OF SCIENCES,
P.N. LEBEDEV INSTITUTE OF PHYSICS (ORDER OF LENIN)
High-energy electron laboratory

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SEARCH FOR ELEMENTARY PARTICLES BEARING A MAGNETIC CHARGE

(An experimental design in the form of a modified variant)

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*) IHEP.

1. STATEMENT OF THE PROBLEM

The experimental search for magnetic particles, which has been in progress for a considerable time, has not produced any positive results[1,2]. The character and technique of all experiments hitherto carried out were determined by the physical representation of the magnetic charge reconstructed by the Dirac theory[2] -- the Dirac monopole (DM). Its main characteristic is the very large value of the charge, which follows from the well-known Dirac relation:

$$\frac{eg}{\hbar c} = \frac{1}{2} \qquad g = 68{,}5e \tag{1}$$

(g is the DM). The high intensity of the electromagnetic processes occurring with the participation of the DM, which is due to the large charge value (in particular, its unusually high ionizing power), should, in principle, have considerably simplified the observation of this particle. The absence of any traces whatsoever of the DM in the experiments which are carried out as accelerators of increasingly large energies are brought into operation, compels us to place its assumed mass at a higher value (the Dirac theory does not make any predictions about the mass of this particle, and the simplest explanation for the absence of the DM in any of the accelerator experiments that the DM mass was too large).

Similarly, the negative results of experimental research into cosmic radiation all indicate a constant decrease in the size of the flux of cosmic monopoles as the experimental technique used to observe them improves. As a result, the progress in DM research has hitherto amounted simply to a shifting of the lower limits on their mass and of the value of their flux from cosmic space; the evolution of these values with the passage of time gives rise to increasing doubt about the existence of the DM.

From this point of view, even more serious doubt about this question is raised by Schwinger's monopole theory, by which

$$\frac{eg}{\hbar c} = 1 \qquad g = 137e \tag{2}$$

At the same time, it should be stressed that current theory does not, at present, provide any grounds whatsoever for rejecting the existence of magnetic charges. The inaccuracy of either of the concrete forms of the magnetic charge theory does not, of course, invalidate the initial premises of this theory (for example, the classical equations of motion). As far as these initial premises are concerned, there is no indication of any internal contradictions in them.

In view of the above remarks, it is advisable to make a stricter analysis of the assumptions on which the DM theory$^{2)}$ and Schwinger's monopole$^{3)}$ are based, so that a more critical understanding can be obtained of relations (1) and (2). This has been done elsewhere$^{4)}$.

The absence of the gradient invariance of both theories, a number of indications of the observability of "strings", compels us to suspect that both theories are not, in substance, magnetic charge theories. As far as relations (1) and (2) are concerned, their derivation in Refs. 2 and 3 is, in substance, closely linked with the presence of "strings", and with the introduction of doubly connected space. In view of this, we might hope that in the magnetic charge theories in which there are no singular potentials on the "strings", the relations for quantization of the magnetic charge of type (1) and (2) will not appear.

It would appear that the considerations which have just been put forward are contradicted by the works of other authors$^{5)}$, in which relations (1) and (2) have nevertheless been obtained without the introduction of any singular potentials. It should, however, be remembered that the proof given in the works referred to was made in semi-classical language. Furthermore, the absence of the Lagrangian and the consequent impossibility of constructing a coherent canonical scheme detracts from the conclusiveness of relations (1) and (2) in these works.

Unfortunately, there is at present not one single magnetic charge theory which is self-consistent or free from difficulties. Consequently, we may consider that the question of the size of the magnetic charge remains unsolved$^{4)}$.

Such a point of view substantially alters possible ideas about the properties of the magnetic charge, and just as substantially alters the technique of its detection. In future experiments, the wisest course is not to search only for magnetic charges whose value is 68.5 e, but to extend the search for particles initially to the region of small values. (From the theoretical standpoint, an attractive value for the magnetic charge would be one which is equal to e or is close to this value.)

Experiments are at present being carried out in connection with the search for the Dirac monopole at the IHEP 70-GeV proton synchrotron$^{6)}$. These experiments presuppose that the monopoles possess fairly large charges. In particular, it is assumed that the experiment which uses the powerful Čerenkov radiation of monopoles will have a significance for monopole charges greater than 17 e.

The experiment proposed below, which was designed under the guidance of M.A. Markov, should broaden the range of monopole charges under examination up to the unit charge, and at the same time complete the experiments which are already being made at IHEP in connection with monopole research. The range of monopole charges in the experiment as planned extends from 1 to 20 e.

2. BEHAVIOURAL CHARACTERISTICS OF MONOPOLES WITH A LARGE CHARGE, USED IN THE WELL-KNOWN EXPERIMENTS FOR THEIR DETECTION

These characteristics are as follows:

a) The particularly large value of the ionization losses, which should exceed the losses of the relativistic electron by 4700 times. The losses to Čerenkov radiation should be just as great. This predicted characteristic of the monopoles has considerably simplified the problem of the background in all experiments. It should be noted that, as Frank$^{7)}$ has pointed out, the polarization of Čerenkov radiation of monopoles must be different from the polarization of electrically charged particles (see also Ref. 6).

b) The large value of the Lorentz force in the magnetic field, as a result of which the energy of the monopole (and its momentum) are easily modified,

$$\frac{dE}{dx}[\text{эв}\cdot\text{см}^{-1}] \simeq 2\cdot 10^{4} H[\text{э}] \qquad (3)$$

This situation should make it possible, even in volumetrically small installations, to produce a separation of the "beam" of the monopoles. The Lorentz force is parallel to the intensity of the magnetic field.

c) The large predicted value of the binding energy of the monopoles with paramagnetic and ferromagnetic substances enabled us to look forward, in a number of experiments, to the possibility of accumulating monopoles in the target over a lengthy period.

However, none of the above-mentioned properties may be used fully when searching for monopoles with a charge value of between 1 and 20 e.

3. WAYS OF IDENTIFYING MONOPOLES WITH SMALL CHARGES

The most significant difference between the behaviour of a small magnetic charge and that of an electrical charge is the direction of the Lorentz force in the magnetic field[*]: the deviation of the monopoles in the magnetic field is along (against) the field. In particular, a monopole with a total energy E and a velocity β, passing through a magnetic field of H Oe perpendicularly to the direction of the field, is deflected along the field at an angle of θ rad, of

$$\theta = \frac{300 g H \ell}{E \beta^2} \tag{4}$$

where g is the charge of the monopole in units of the electron charge, and ℓ is the length of the magnetic field in centimetres.

In this way, the recording apparatus, which is placed at an angle θ to the initial direction of monopole motion will, generally speaking, be sensitive to monopoles of various masses, velocities, and charges which satisfy the relation:

$$A = \frac{\beta^2 E}{g} = \frac{\alpha}{g} = const = \frac{300 H \ell}{c} \; [\text{эв}] \tag{5}$$

---

[*] No consideration is taken here of the Lorentz force acting on a monopole with a small magnetic charge moving in an electric field, since it is extremely small, even in fields having an intensity of up to 100 kV cm^{-1}.

This property of the monopoles forms the basis of the projected experiment. The choice of A should be made in the light of the following considerations. Increasing A shortens the range of magnetic charges sought simultaneously in the same experiment, and increases the difficulties of separating the "beam" of monopoles (particularly those monopoles which are brought about at an angle in the vicinity of 0° in relation to the primary beam).

At the same time, it is clear from kinematic considerations that the likelihood of the creation of monopoles of sufficiently large mass with a small value $\alpha = \beta^2 E$, is, in exactly the same way, equal to zero. Consequently, it is desirable to choose A in the region of 3×10^9 eV for the basic "review" experiment which will enable the first assessments to be made of the production cross-section of monopoles with a charge of between 1 and 20.

As also in the case of the generation of other particles which are produced in pairs, the maximum possible mass of the monopoles which may be produced by protons with an energy of 70 GeV (without taking into account the Fermian motion of nucleons in a heavy nucleus) does not exceed 5 GeV. For an evaluation of the relative yield and energy spectrum of particles of various masses, it has been proposed, as is usually the case[8-11]), that the production cross-section in the centre-of-mass system is isotropic and that the energy distribution between particles in the final state is equally probable.

Calculations showed that when the magnetic channel is tuned to $A = 3 \times 10^9$ eV, the range of charges and masses which will be investigated in the experiment will be as shown in Fig. 1.

The apparatus will then have a maximum sensitivity to monopoles with $g \simeq 10$.

The dependence of the probability of the production of monopoles $S(\alpha)$ from $\alpha = p\beta$, for various masses of monopoles, is given in Fig. 2. Figure 3 shows similar curves for $m = 4$ GeV/cm^2, corresponding to various angles of monopole emission in the laboratory system.

Apart from the above-mentioned behavioural characteristics of monopoles with a charge of 1 to 20 e in a magnetic field, it is assumed below, on the basis of the projected experiment, that the energy losses by the monopoles and their scattering occurs in exactly the same way as for electrically charged particles with Z from 1 to 20. These limitations on the charge of the monopole determined the choice of the thickness of the target, the thicknesses of the scintillators in the control counters, etc.

4. GENERAL DESCRIPTION OF THE EXPERIMENT

The layout of the magnetic channel is shown in Fig. 4. It is proposed to use the standard IHEP magnetic equipment in the channel. It is assumed that the beam of monopoles will be deflected in a horizontal plane, and it is consequently proposed to rotate the C-type SP-032 magnets so that they lie on their backs. The quadrupole magnets for focusing the beam of magnetically charged particles must be rotated around their axis through an angle of 45° in relation to the horizontal.

The extracted 70 GeV proton beam is focused onto a spot with a cross-section of $2 \times 2\ \mathrm{mm}^2$ on a target, the thickness of which is of the order of 0.1 of the nuclear length. In the horizontal plane, the channel collects particles which are emitted at an angle of 0.003 rad to the proton beam.

A doublet input lens (composed of two magnetic quadrupole lenses) placed in the immediate vicinity of the target, provides a large solid angle of particle capture from the target into the channel.

Behind the input lens is situated a collimator, which limits the aperture of the beam of secondary electrically charged and neutral particles which form the background in our installation.

Each of the magnets M1 and M2 (type SP-032) turns the "beam" of monopoles through 50 mrad.

Behind the M1 magnet is situated a system of collimators. One of these limits the aperture of the "monopole" channel, whilst another collimates once more in the beam of secondary particles. The field lens KL3, in conjunction with magnet M2, compensates for the linear and angular dispersion of the magnetic channel caused by the deflection in magnet M1, and provides a high transmission level for the channel in the range of transmission values $\alpha = \beta pg$.

The output lens (KL4, KL5, and KL6) shapes the beam on entering the measurement aperture.

The arrangement and operating characteristics of the elements of the channel are given in Table 1. Figure 5 shows the profile of the beam in two planes. The phase characteristics of the beam at the point where the recording apparatus was situated is shown in Figs. 6 and 7. The calculated beam dimensions at the point where the experimental layout was situated are 12 × 12 cm^2, and, as a first approximation, are determined by the chromatic aberrations of the channel.

Figure 8 shows the dependence on momentum of the solid angle of monopole capture in the channel.

The design calculations of the magnetic channel were made at IHEP with a MOPS[12)] and FAZAN[13)] programme.

As can be seen from Fig. 1, when the magnetic channel is tuned to $A = 3 \times 10^9$, monopoles with charges close to the unit charge and a mass of 3-4 GeV/c^2 cannot penetrate into the recording apparatus. To enable the experiment to cover also this range of charges and masses, it is proposed to envisage the possibility of re-tuning the channel to A = 12 GeV, which will enable more detailed studies to be made of the range of charges from 1 to 5. Re-tuning the channel to A < 1 GeV will provide the possibility of investigating the interesting case of monopoles which, although possessing a large charge and consequently being affected strongly by the magnetic fields, nevertheless produce a relatively weak ionization, comparable with the ionization of the usual relativistic electrically charged particles.

Both in the design of the channel and in the choice of the arrangement and thickness of the various elements of the recording apparatus, account was taken of the ionization losses and multiple scattering of the monopoles in the most unfavourable recording conditions, i.e. when g = 20 and p = 60 GeV/sec.

5. OVERCOMING THE BACKGROUND

The requirements concerning the background are dictated by the following considerations:

1. The over-all particle flux through spark chambers with a surface area of about 500 cm^2 must be less than 10^6 particles/sec.
2. The particle flux which passes through the entire installation along the channel as a result of repeated scattering must be kept to a minimum in order to reduce erroneous triggering of the spark chambers. The maximum number of times erroneous triggering is permitted is 10 per second.

The main source of the background in the region of the experimental installation is the beam of high-energy particles downstream from the target. It consists of a beam of secondary particles produced in the target, and protons which do not interact in it. If we assume that the beam passes through the air without any shielding, the anticipated loading at a distance of 4 m from the beam is $\approx 10^5$ cm^{-2} sec^{-1} for a permissible level of about 10^3 cm^{-2} sec^{-1}. It is therefore necessary to place shielding between the beam and the apparatus, which will reduce the background by about 100 times.

In order to achieve this reduction, it is sufficient to place 3.5 metres of concrete between the beam of secondary particles and the installation. As an additional measure, it can be enclosed in a vacuum tube. It should be noted that the few metres of beam directly opposite the installation is the most dangerous section.

To reduce spurious triggering, the monopole beam and the secondary beam are collimated.

The most severe requirements are imposed on the collimation of the beam of secondary particles at the input into the magnet M1, since, if the collimation is bad, the particles which are emitted from the target and are scattered on the poles of this magnet may be the principal source of the background in the channel. To reduce the background, it is necessary to prevent the particles which are emitted from the target from striking the poles of the magnet directly. To simplify this, the axis of the channel is rotated around the axis of the primary beam through an angle of 3 mrad, in such a way that the axis of the secondary beam lies in the median plane of the magnet, whilst the axis of the channel is "squeezed" up against one of the poles. The collimator K acts as a screen to prevent the beam of the target from directly striking the poles of the magnet. Consequently with this design, the background of the channel behind magnet M1 can be produced only by particles which have undergone at least two interactions after the target. It may be expected that in these conditions the flux of background particles through KL3 will not exceed 10^7 particles/sec (for a primary beam intensity of $\sim 10^{12}$ protons $\sec^{-1}$). These evaluations were made using, as was done above, the results of the work quoted in Ref. 11.

Loading of the channel behind magnet M2 is determined both by the beam scattered in magnet M2, and the beam which has been scattered on the second collimator in the secondary beam and has passed through the shielding. The location of the steel screen, which is about 4 metres thick and has a cross-sectional area of ~ 0.3 m^2 should reduce the background in the channel behind the second magnet up to a value of the order of 10^5 particles/sec provided that about 10^{13} particles/sec are eliminated in the collimator.

6. RECORDING APPARATUS

It is assumed that the monopoles will be identified by their characteristic change in the direction of motion by an angle of the order of 0.025 rad after passing through magnet M3.

The main recording instrument must be the spark spectrometer at the base of magnet SP-56 (magnet M3). The system, which consists of eight wire spark chambers, is situated in the immediate vicinity and on both sides of the magnet, and enables reliable measurements to be made of the direction of the particle trajectories at the input into the magnet and at its output, with an accuracy of not less than 0.003 rad (the base is about 1 m). The data from the spark chambers will be recorded in an intermediate memory (on a magnetic drum). The spark chambers must be triggered by a system of scintillation counters broken down into three groups. The first group of counters, C_1, is placed in front of magnet M2, the second in front of the spark chambers, and the third behind the spark chambers, about 5 metres behind magnet M3.

In this way, the triggering pulse to the chambers will arrive only if random coincidences are present, or if a particle experiences two deflections in the magnets at the requisite angle. In order to assess the number of random coincidences, we shall use the background evaluations referred to above. It is assumed that each group of counters acts as a telescope of counters set for rapid coincidences (5×10^{-9} sec) and as systems of anticoincident counters, so that the load of the group is approximately equal to the load of a given section of the channel.

In this case, it is expected that the number of erroneous triggerings of the system will be of the order of 3-5 sec^{-1}, even with a resolving time of the coincidence circuit between groups of $\approx 5 \times 10^{-8}$ sec.

In order to increase the efficiency of recording heavy particles with a small charge, it is necessary to increase the resolving time of the system sharply, since particles with a mass of ≈ 2 GeV and a charge of ∿ e will, in our "review" experiment, have a velocity of about 0.8 C and will lag behind light, extreme-relativistic particles by 25 msec over a base length of 30 metres.

This places a restriction on the high-speed operation of the circuits used. As an additional selection criterion, it is proposed to use the technique of comparing the time-of-flight over two base lengths, as proposed in IHEP[14].

In this way, the proposed system of recording monopoles should make it possible to obtain, during the measurements, a fairly small number of events which can be subjected to a detailed investigation, and to exclude the erroneous identification of events.

7. EXPECTED RESULTS

As has already been pointed out, the greatest sensitivity in the "review" experiment corresponds to a value of the possible charge of about 10 e. The dependence of the efficiency of the channel on monopoles of various masses and charges is shown in Fig. 9.

The thickness of the target (∿ 10 g/cm^2) is chosen in such a way that the monopoles with the largest charges permissible in the experiment (∿ 20) did not lose more than 10% of their energy. It is proposed to use targets with small Z, e.g. carbon, beryllium and aluminium.

When this type of target is irradiated with protons for a hundred hours (the mean intensity being 3×10^{11} protons/cycle), it is possible to obtain upper limits of the monopole production cross-section at a 95% level of reliability, which for $g = 10$ and $m = 1$ GeV/c^2 are:

$$\sigma\ 95\% = 10^{-37}\ \mathrm{cm}^2/\mathrm{proton}$$

and for $g = 10$ and $m = 4$ GeV/c^2:

$$\sigma\ 95\% = 10^{-38}\ \mathrm{cm}^2/\mathrm{proton}\ .$$

Similar results for $g \simeq 2.5$ and $g \simeq 70$ may be obtained from experiments with other values of the guide fields in the channel, for a total time of the order of 200 hours of accelerator operation. It is expected that the upper limits of the cross-section for the intermediate charge values will have similar values.

In this way, during a time of about 300 hours, it is possible to study a range of possible monopole charges from 1 e to 70 e in a range of masses extending from 4.8 GeV downwards.

APPENDIX I

CALCULATIONS OF THE MOMENTUM DISTRIBUTION OF MONOPOLES

The calculations of the momentum distribution of monopoles in the $p + p \rightarrow p + p + g + \tilde{g}$ reaction were carried out on the basis of the conclusions of the statistical theory, on the assumption that there is no interaction between secondary particles, and that the likelihood of any combination of the momenta of secondary particles is determined only by the phase volume$^{10)}$. In the formulas given below, the designations of this latter work are used.

The likelihood of the emission of a particle in the centre-of-mass system, having a momentum p_n^* , is proportional to the product of the square of the momentum of this particle by the value of the phase volume occupied by (n-1) particles:

$$\frac{1}{N^*}\frac{dN^*}{dp_n^*} = S^* = A p_n^{*2} R_{n-1}\left(-p_n^*, E_c - \sqrt{p_n^{*2} + m_n^2}, m_1, m_2, \ldots, m_{n-1}\right) ,$$

where A is the coefficient of proportionality:

$$A = \frac{1}{\int_0^{p_n^*(max)} \frac{dN^*}{dp_n^*} dp_n^*} = \frac{1}{\int_0^{p_n^*(max)} p_n^{*2} R_{n-1}(\ldots) dp_n^*} .$$

The Lorentz-invariant phase volume occupied by (n-1) particles for n = 4 is:

$$R_3\left(-p_4^*, E_c - \sqrt{p_4^{*2} + m_4^2}, m_1, m_2, m_3\right) = R_3(0, \mathcal{E}_c, m_1, m_2, m_3);$$

where

$$\mathcal{E}_c = E_c^2 - 2E_c E_4^* + m_4^2$$

For

$$m_1 = m_2 = M = 0{,}938\ \text{Гэв},\ m_3 = m_4 = m,\ p_4 = p$$

we have

$$R_3(0, E_c, m, M) = \pi^2 \int_0^{p_3^{*(max)}} \frac{p_3^{*2}}{E_3^{*}} \sqrt{1 - \frac{4M^2}{E_c^2 - 2E_c E_3^{*} + m^2}}\, dp_3^{*},$$

where

$$p_3^{*(max)} = \frac{\sqrt{[E_c^2 - (2M+m)^2][E_c^2 - (2M-m)^2]}}{2E_c}$$

$$A = \frac{1}{\int_0^{p^{*(max)}} p^{*2} R_3(0, E_c, m, M)\, dp^{*}}$$

In the laboratory system of coordinates, the likelihood of the emission of a monopole with a momentum p at an angle θ in relation to the direction of the incident beam of protons is:

$$S = \frac{1}{N}\frac{d^2N}{dp\,d\mu} = \frac{1}{2} A p^{*2} R_3(0, E_c, M, m)\, y \quad ,$$

where μ = cos θ, y is the Jacobian of transition from the centre-of-mass system to the laboratory system:

$$y = \frac{\gamma[\sqrt{p^2+m^2} - pV\mu]p^2}{[\gamma^2(\sqrt{p^2+m^2} - pV\mu)^2 - m^2]\sqrt{p^2+m^2}} \quad ,$$

$$p^{*2} = p^2[\gamma^2(\mu - \frac{V}{p}\sqrt{p^2+m^2})^2 + (1-\mu^2)] .$$

Since it is convenient to use the value $\alpha = \beta^2 E$ for future calculations of the output, the value $\alpha = p/\sqrt{1 + m^2/p^2}$ has been used in the computer calculations instead of the momentum p. For each value of m and θ, the value $S(\alpha)$ was calculated. The calculations were made on a FIAN computer, and the results of the calculations of the momentum distributions of the monopoles are shown in Figs. 1 and 2 for the values

$$m = 0.2;\ 1;\ 3;\ 4;\ 4.5;\ 4.8 \text{ and}$$
$$\theta = 0^\circ,\ 1^\circ,\ 2^\circ,\ \ldots,\ 5^\circ\ .$$

The calculations of the momentum distributions of the monopoles by means of Lorentz invariant phase volume agreed, with a good degree of accuracy, with the calculations made on the basis of the formulas from work of Amaldi et al.$^{11)}$.

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Table 1

Arrangement and operating characteristics of channel elements

Element	Field or field gradient			Effective length (cm)	Aperture (height × width) (cm^2)	Distance from target to centre of the element (metres)	Type of magnet or lens
	A = 3	A = 12	Possible limits of variation				
KL$_1$	321 G/cm	1283.8 G/cm	1300 + 60	208	12.6 × 12.6	3.3	20 × 200
KL$_2$	196.6 G/cm	786.2 G/cm	1300 + 60	208	12.6 × 12.6	5.6	20 × 200
K$_1$				100	15 × 8	7.6	
M$_1$	1564	6256 G	13500 + 600	320	14 × 20	12.4	SP-32
K$_2$				300	16 × 16	20	
KL$_3$	118.75	475 G/cm	1300 + 60	108	12.6 × 12.6	28.4	20 × 100A
M$_2$	1564	6256 G	13500 + 600	320	14 × 20	44.4	SP-32
KL$_4$	100	400 G/cm	1300 + 60	108	12.6 × 12.6	47.7	20K 100A
KL$_5$	298	1192.2 G/cm	1300 + 60	108	12.6 × 12.6	49.3	20K 100A
KL$_6$	263.7	974.9 G/cm	1300 + 60	108	12.6 × 12.6	50.9	20K 100A
M$_3$	3000	12000 G	13500 + 600	80	20 × 50	72.9	SP-56

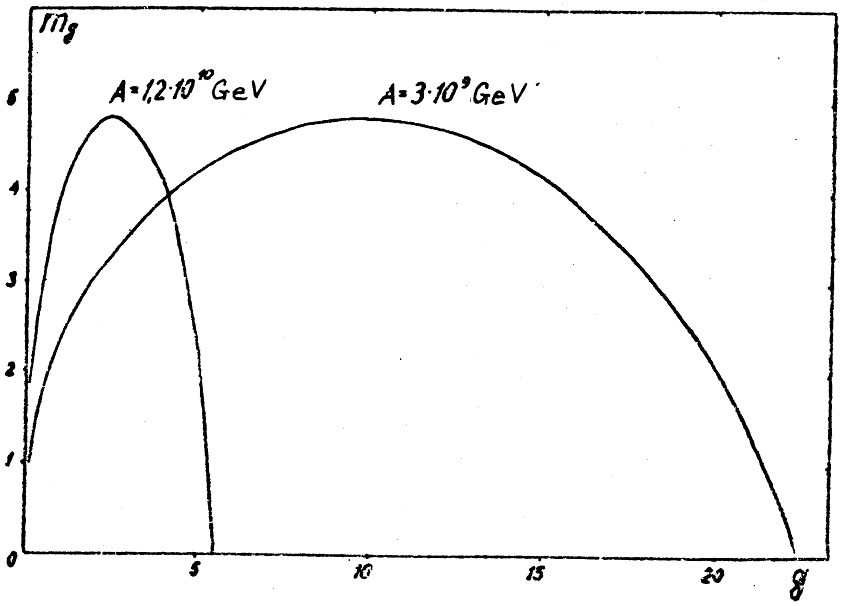


Fig. 1 Range of monopole charges and masses investigated.

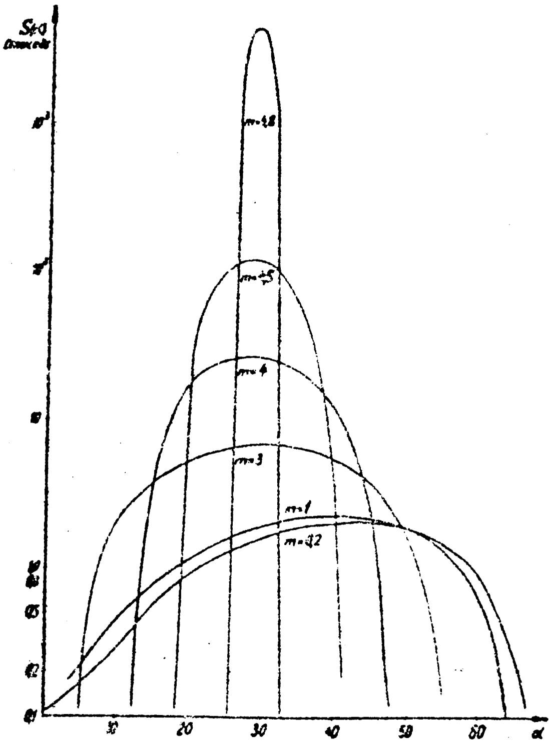


Fig. 2 Momentum distribution of the monopoles of various masses for an emission angle $\theta = 0°$.

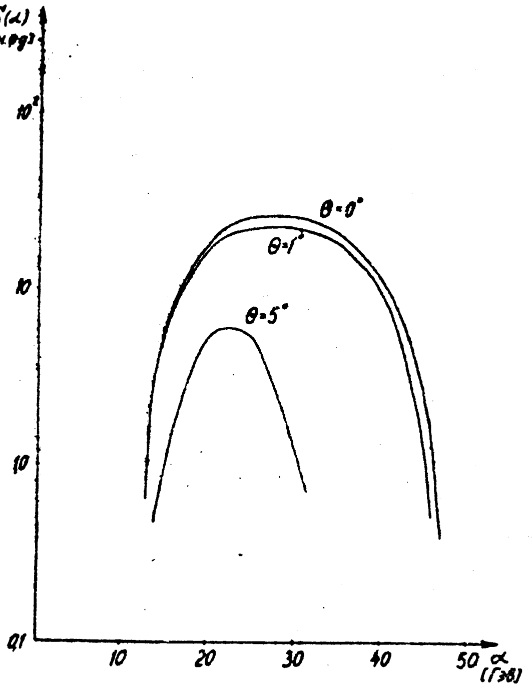
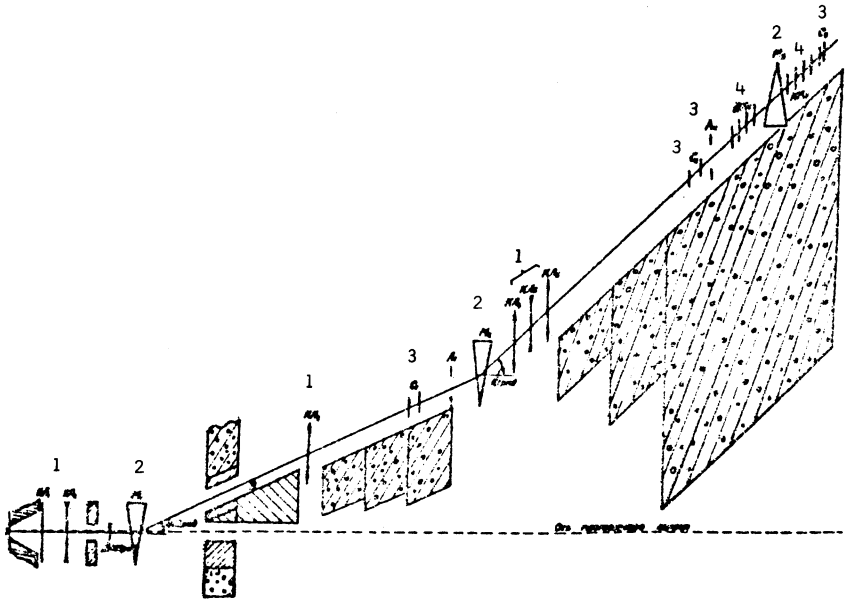


Fig. 3 Momentum distribution of monopoles with a mass m = = 4 GeV for emission angles of θ = 0°, 1° and 5°.



1: Magnetic lens;

2: Magnet;

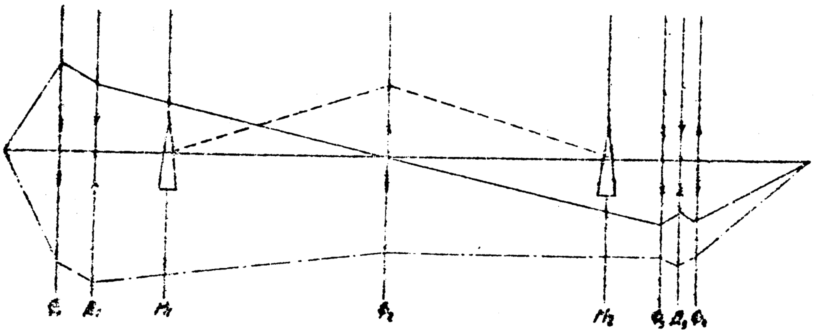
3: counter;

4: spark chamber.

Vertical scale : ⊢——⊣ = 1 m

Horizontal scale: ⊢——⊣ = 10 m

Fig. 4 Layout of the magnetic channel.



—— Particle trajectory with A = A_0 and maximum deflection in a horizontal plane.

--- Axial trajectory of the particles with A = A_0 + ΔA ΔA > 0.

-·- Particle trajectory with A = A_0 in a vertical plane.

Fig. 5 Profile of a beam of monopoles in the horizontal and vertical planes.

2 metres in front of SP-56

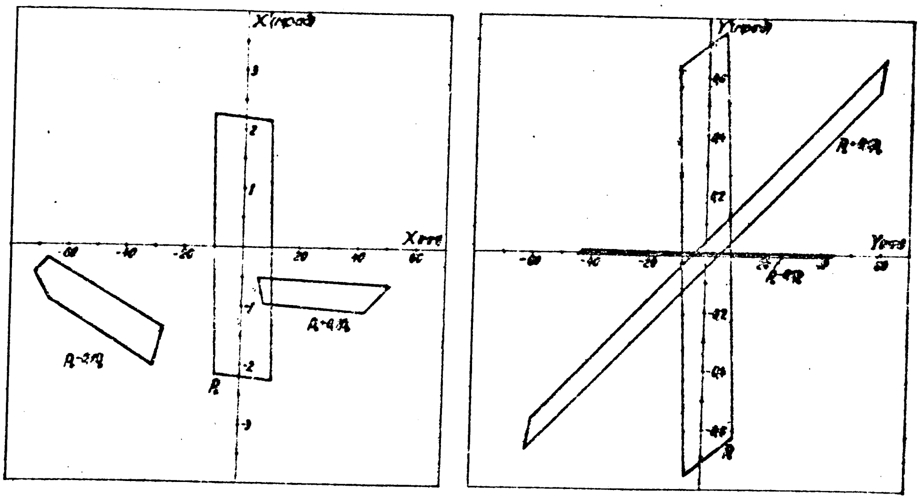


Fig. 6 Phase characteristics of a "monopole" beam at the input of the recording apparatus.

5 metres behind SP-56

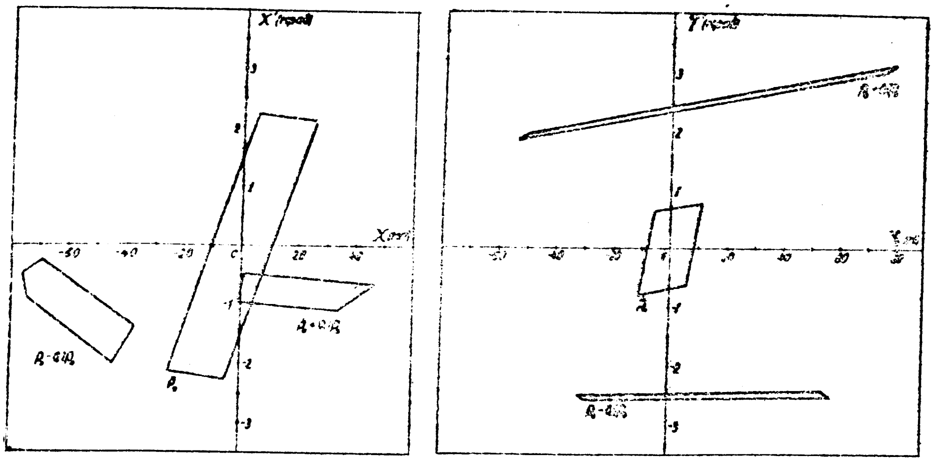


Fig. 7 Phase characteristics of the beam at the exit of the recording apparatus.

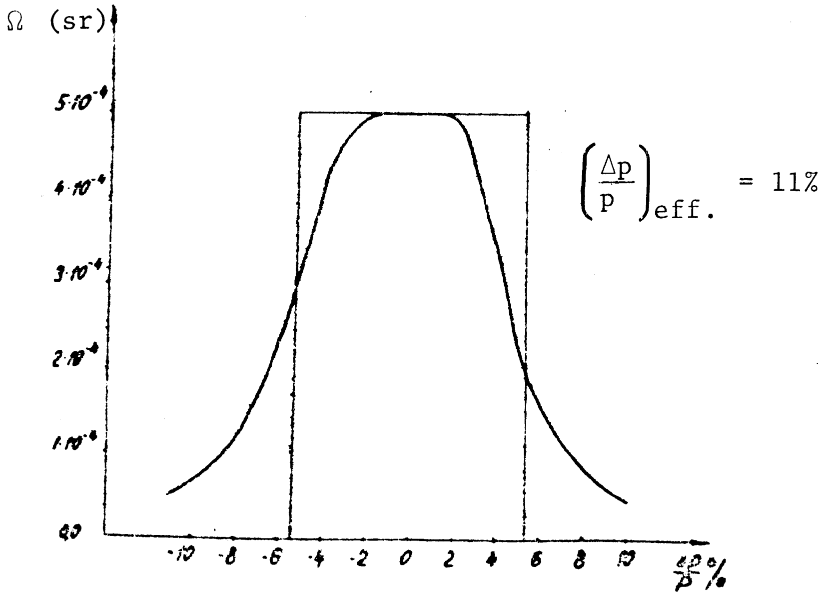


Fig. 8 Dependence of the solid angle of monopole capture in the channel on the monopole momentum.

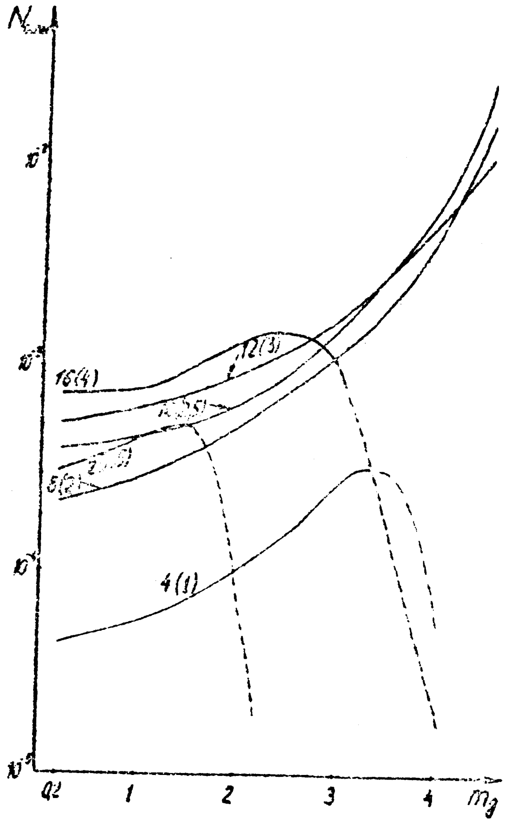


Fig. 9 Efficiency of the channel with respect to monopoles of various masses and charges.