Observation of the magnetic charge effect in experiments with ferromagnetic aerosols

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RESUME. The experimental investigations of a ferromagnetic aerosol's behaviour in magnetic and electric fields of various configurations are described. It has been stated that number of aerosol particles under intensive ilumination move in the magnetic field as an object carrying a magnetic charge.

In the present review a series of experiments is described, which is performed for the purpose to investigate the effect, discovered by austrian physicist Felix Ehrenhaft, which, according to his interpretation, is directly related to the problem of magnetic monopole. Rather full bibliography of Ehrenhaft's works is represented in [1].

Ehrenhaft had begun his investigation before P.A.M. Dirac published his basic paper on monopole theory [2]. Yet in 1930 Ehrenhaft reported that he observed an effect, the essence of which is that separate aerosols particles, obtained by means of dispersion of electrodes arc material at the presence of the intensive light beam in a homogeneous magnetic field, move like objects, carrying a magnetic charge (according to Ehrenhaft's terminology single magnetic poles)[3]. Ehrenhaft's works, in which he has invariably reproduced the effect and has confirmed his results, were published within more than twenty years, but recognition of magnetic charge discovery didn't come (there are 65 titles of Ehrenhaft's works in bibliography [1], much of them are experimental).

After Ehrenhaft similar experiments were performed in other laboratories, but only some of the investigators managed to reproduce the effect [4]. As a result, various interpretations of the phenomenon [5], often contradictory ones, were proposed. Among the latest works, investigations by Ferber[6] and Shedling

[7], to our opinion, are the most interesting. They confirmed Ehrenhaft's observations and conclusions. In the paper [6] the value of the supposed magnetic charges of aerosol particle has been estimated on the basis of studying the regularities of their movement in a homogeneous field of a permanent magnet. The obtained values of charge are in the range of $10^{-11} \sim 10^{-14}$ gauss . cm^2. Shedling investigated the behaviour of particles weighted in gas in rectilinear current conductor field. He observed the particles movement , normal to the conductor radius, and reported the magnetic charge of $10^{-9} \sim 10^{-12}$ gauss . cm^2.

As is seen from the given estimations these results are in contradiction to the Dirac quantum condition [2] known at that time

$$\frac{g_D \cdot e}{c} = \frac{n\hbar}{2} \tag{1}$$

from which it follows that the magnetic charge (at n=1) cannot be less than $g_D = 3,28 \times 10^{-8}$ gauss.cm^2 ($e, c, \hbar$ are the electron charge, the velocity of light and Planck constant respectively).

Probably, this contradiction was one of the basic reasons for which the interest for Ehrenhaft's works died away soon after his death, and now they are practically forgotten.

Vagueness of the situation, contradictory interpretations of the effect, and, moreover, its full negation by some investigators induced us, in accordance with general interest to the monopole problem, to reproduce and continue investigations in this direction. Our nearest aim is to get convinced in the existence of the effect itself.

2. Experimental installation and methods of observations.

To investigate the effect an installation was made, the construction and performance of which are shown in Fig.1. The airtight chamber (1) together with the flask which plays the role of aerosol source (2), is evacuated through a system of cocks and pipes (3-6) until a high vacuum is achieved and filled with working gas up to atmospheric pressure. Aerosols are obtained when one dusts the material of the sparking contacts (7) of the electromagnetic current interrupter (8). With the help of cocks (3) and (4) the gas together with the aerosols is transported from the flask (2) to the working chamber (1). Lighting of the aerosol is performed by He-Ne laser with $\simeq$1 W power.The light of this laser, having passed through the accessory neutral filters of various density (10), the optical system (II) and the input window (12), is focused in the field of view of a microscope (13). The light flow density in the focus of our installation is about $10^3 \mathrm{W/cm}^2$. Having passed through the chamber the light flow is measured by photoresistor (14). The choice of a laser as a light source is motivated by the absence of an infrared component because at the camera warming up the conventional fluxes, occuring in it, make the measurements impossible. Coherence and light polarization in this case do not play any role; to observe the effect one may use some other sufficiently powerful, light source, however infrared radiation ought to be filtered. The scanning unit (15) allows to subject aerosols to a magnetic and an electric field, perpendicular to him. As is shown in Fig.1, where (16) denotes the ferrite pole heads of electromagnet (17), (18) denotes the plates of the electrostatic condenser and (19) denotes the insulators. The range of fields intensity changing in the installation is $H = 0 \sim 200$ gauss, $E = 0 \sim 1000 \mathrm{Vcm}^{-1}$. Events are registrated by a 10 time magnification microphotocamera. The plane of the camera image is parallel to the sketch plane in Fig.1.

3. Experiment with a homogeneous magnetic field.

3.1. Preliminary investigations.

First observations of ferromagnetic aerosols (iron, nickel, cobalt) performed in an argon atmosphere, confirmed Ehrenhaft's reports. On the backgrounds of particles which make in an ordinary brownian movement not reacting to the magnetic field, separate particles, simultaneously with the change of the field direction vacillated along its field lines, each of them with its own amplitude.

Fig.2 schematically shows the trajectory of such a particle,registrated on a photoplate at the time of exposition of some seconds and with a frequency of the current switching in the electromagnet winding (17, Fig.1) equal to 7 Hz.

So, we have reproduced the effect , the essence of which is the following: at the intensive lighting separately weighted in gas ferromagnetic particles moves in a homogeneous magnetic field along its field lines. The change of an intensity vector or direction $\vec{H}$ to the opposite one causes immediate change of the direction of these particles movement to the opposite direction as well, and the field switching off – their stoppage. Increase of the field intensity or the light beam intensity causes the increase of particle velocity and vice versa, at their decreasing the particles velocity decreases as well. The number of particles, moving in the direction of the vector $\vec{H}$ with accuracy up to the error of measurement, is equal to the number of particles moving in the opposite direction.

We have investigated aerosol behaviour of about thirty various substances. The effect was observed only on ferromagnetics. Ehrenhaft's report [3] that he observed the effect in bismuth, antimonium and selenium, was not confirmed by our experiments.

In order to find out the possible influence of the particle surface state on the effect, various agressive addenda have been introduced into the working gas (by means barbotagging). It has been determined that the vapours H_2O, I_2, Br_2, HCL, HNO_3, NH_4OH etc. and the presence of oxygen, and the change of argon to air do not suppress the observable effect. So one can make a conclusion that the effect is not determined by the particle surface condition.

Our further investigations have been performed with aerosols, obtained by ferrum dispersion in an argon atmosphere.

3.2. Quantitative characteristics

The basic question, which we put forward before starting the investigation was the question of the particle energy source. The cause of particles movement can be both the light, and the magnetic field. To solve this alternative we investigated the dependence of the particle mean-quadratic velocity in an ensemble (of the kinetic energy) on the density of the light beam Φ at the constant intensity value of the magnetic field H and on the field intensity at the fixed value density of the light beam Φ. In order to obtain the sufficient statistic support in both cases more than 800 particle trajectories have been treated. Experimental results are presented in Fig.3.

The mean-quadratic velocity of particles is an energy characteristics and is proportional to the particles mean energy in the ensemble. At the stationary movement in gas the particle velocity does not depend upon its weight, and is determined by the braking coefficient K, which, in its turn, depends upon the form and size of the particle. Its relation with mass through the density cannot be considered to be strictly determined. So, in future, we will consider the velocity of the particle v_i and its mass M_i as random independent values, and we think, that

$$\frac{1}{n}\sum_i \left(Mv^2\right)_i = \bar{M}\cdot\bar{v}^2 \tag{2}$$

where n is the particles number in the ensemble.

Let us analyze the possibility of explaining the phenomena in relation to gas-dynamical effect, connected with the warming up of the particle by light beam. Energy balance, of the process in this case can be written down in the form:

$$dW_k + dW_{br} + dW_R + Qdt + dW_{in} = \gamma\sigma\Phi dt \tag{3}$$

where $W_k = \frac{Mv^2}{2}$ is the particle kinetic energy, $dW_{br} = Kv^2$ is the work against braking strength, $W_R \simeq T^4$ are radiation losses, Q is the flux of the particle energy dispersion on the account of heat conductivity of the gas, $dW_{in} = CMdT$ is the inner particle energy, determined by the temperature T, γ is a light absorbtion coefficient, σ is the particle geometrical section, Φ is the light flow. The correctness of eq. (3) is determined by the contribution to the process of nonlinear effects two-stepped etc. processes of the light absorption. For the largest value of flow in our experiments $\Phi = 5.10^3\mathrm{Wcm}^{-2}$ (the intensity of the electric compound of the light beam $E = 2.10^3\mathrm{V.cm}^{-1}$) probability relation of the two-stepped processes to the one-stepped $W_2/W_1 \simeq (E/E_{at})^2$ (here $E_{at} \simeq 10^8\mathrm{Vcm}^{-1}$ is the inner-atomic electric field) to the order of the value equal to 10^{-10}.

In the established regime $T =$ constant, $v =$ constant (the latter follows from the Stoke's character of movement and is observed experimentally). Besides, $W_R \ll W_{br}$, at the particle temperatures existing in this experiment. Thus, eq.(3) is simplified as :

$$Kv^2 + Q = \gamma\sigma\Phi \tag{4}$$

and the task is to calculate the dependences $Q(\Phi)$. As a result of trivial but somewhat long calculations [8], and substituting the obtained result into (4) we get the relation of particle velocity to light flux in the form:

$$\frac{d(v^2)}{d\Phi} = \frac{B}{K_0(T_0^{3/2} + A\Phi)^{1/3}}\left\{1 - \frac{A}{3(T_0^{3/2}/\Phi + A)}\right\} \tag{5}$$

Here T_0 is an absolute working gas temperature, K_0 is the particle friction coefficient in gas at the temperature T_0, A and B are the constants, determined by the particle size and its thermodynamical characteristics.

As is seen from (5), functional dependence $v^2(\ )$, obtained under supposition that the light beam is an energy source of the particle movement, contradicts the dependence obtained experimentally, as at $\Phi \to 0$, the derivative

$$\frac{d(v^2)}{d\Phi} \to \frac{B}{T_0^{1/2} K_0}$$

and at $\Phi \to \infty$, $d(v^2)/d\Phi \to 0$.

The experiment shows that with the increase of the light beam power the kinetic energy of the particle increases rapidly. It must be at gas-kinetic interactions (Fig.3-a), i.e. in this case the light beam does not support energetics of the observable process. As a result, any model based on the supposition that the particle energy source is the light is baseless. It means that such effect as radiometric, "reactive" [5], "aero-dynamical screw", light pressure etc. cannot be responsible for the observable phenomenon, because they lead to a contradiction with the experiment, and, as a consequence, to the violation of energy conservation law.

The other possible source of particle energy may be a magnetic field only, but then it is necessary to assume that the particle possesses the charge G . In this case the equation of particle movement is written down as follows :

$$M\frac{d^2\vec{R}}{dt^2} + K\frac{\vec{dR}}{dt} = G\vec{H} \tag{6}$$

where M and G are a mass and a magnetic charge of the particle.

The solution of this equation at $\vec{H} = const$ for the velocity derivative directed along the field

$$v = \frac{GH}{K}\left[1 - \exp(-\frac{K}{M}t)\right] \tag{7}$$

at $Kt \gg M$, which is observed in the investigation, leads to the expression:

$$v = \frac{GH}{K} \tag{8}$$

i.e. at the constant charge G the particle velocity v must be proportional to the intensity of the magnetic field H.

However the move of the experimental curve $v(H)$ (Fig.3-b) cannot be described by a linear function. Both in our experiment [8], and in early papers by Ehrenhaft [9] it is marked that at the magnetic field $H \simeq 5$ gauss the effect of the velocity "saturation" is observed, i.e. proportionality between the particule velocity and the magnetic field intensity is disturbed. This fact may be explained by assuming that the particle magnetic charge value is decreased with an increasing of the external magnetic field because of cold emission, arising already at $H \simeq 5$gauss on account of that the binding energy of unit charge with the particle has the value comparable with kT [10]. More detail about this problem we shall discuss further.

4. Particles morphology

Investigation of the form and determination of the particle size have been performed with an electronic microscope. Simultaneously with the methods of electronography the structure of the crystal lattice has been investigated. Preparation was received by the direct aerosol sedimentation, obtained by electroerosive Fe dispersion in an argon atmosphere, on a molybden substrate directly in the working volume of the camera of the experimental installation (Fig.1). It allows us to confirm that particles distribution according to their value on the preparate and in gase suspension, where the discussed phenomenon has been observed, are identical.

The photographs obtained in a passing electron at magnification of 400000 power have shown that all the particles have the form close to the spherical one (with a $10^{-5} \sim 10^{-6}$cm) with outlining cut.

By means of electrographic analysis it is determined that the particles have a cubic face-centred lattice with a magnetite parameters of Fe_3O_4. Magnetite aerosol at Fe dusting in an argon atmosphere has been observed by other investigators [11]. The process of ferrum oxidation owing to a pyrophority of particles of a submicron size occur actively even in the presence of a comparatively small oxygen impurity.

On the photographs there are seen unions of magnetite particles forming long, up to some μ, chains which are similar to those described in [12] for the analogous size particles. The evaluation of the velocity of such chains formation directly in a weighted state on the condition that the particles are magnetized up to the saturation domains, leads to conclusion that in a weighted state the observable chains, during the experiment, cannot be formed, i.e. the particle agglomeration occurs on the base surface. Particles distribution according to their value is illustrated by histogram in Fig.4 made taking into account results of measurements of 600 particles diameters.

5. Magnetic charge value determination

Among the particles which demonstrate the phenomenon of the magnetic charge, there is sufficiently large number of particles, carrying an electric charge as well [13, 14]. It allows one to compare the forces according to their value, which influence the particle on the side of the magnetic H and electric E fields, i.e. as a result, the electric q and magnetic G charges of the particle.

In the installation (Fig.1) the vector of the fields intensity are in the same plane parallel to the plane of the photographic unit images. The electric field is parallel to the gravitational force, and the magnetic field is parallel to the light beam Φ : $(E \perp H)$. The experiment geometry and the particle trajectory in this case are shown in Fig.5.

The frequencies of the fields switching have the ratio as 2:1 and a fixed mutual phasing. It allows to exclude completely the error in track identification because such tracks are observed in the mode of this experiment only. It also allows to distinguish the particles, moving along and against the vector direction of the magnetic field intensity, i.e. to determine magnetic charge sign.

In the experiment more than 1200 tracks of particles have been photographed and analyzed for some regimes, which correspond to various relations of E/H. Characteristic particles distribution according to the velocity projections in vectors direction E and H at the relation $E/H = 1,01 \times 10^{-2}$ is given in Fig.6. Experimental points perfectly cover the curves of the type $a.v\exp(-bv)$ (the curves in Fig. 6).

Identical character of microparticles movement in the electric and magnetic fields, expressed as v_E and v_H distributions means that these particles at light beam existence possess equal properties with respect to the pointed out fields. It allows us to suppose that the cause of their movement in both cases may be one and the same, i.e. field interaction with a corresponding charge. Forces, influencing the particles in this case, can be formally expressed through the charges:

$$F_E = K_E = qE \qquad F_H = K_H = GH \tag{9}$$

from which it follows that

$$\frac{G}{q} = \frac{E \cdot v_H}{H \cdot v_E} \tag{10}$$

It means that the relation of a magnetic charge value to the electric one G/q for this concrete particle does not depend upon the Stoke's coefficient K, which is defined by the particle size and which is a stumbling-stone of the greatest part of Ehrenhaft's opponents [1].

It appeared to be possible to express the numerical values of a relation G/q defined for 1200 particles according to the values of their velocities v_H and v_E, which have been found experimentally through a constant of fine structure $\alpha = 1/137 = 7,3 \times 10^{-3}$ as a empirical formula:

$$\frac{G}{q} = \frac{n}{2} \cdot \frac{\alpha}{3} \tag{11}$$

where $n = 1, 2, \ldots$ is a whole number. Statistical criteria of the experiment correlation with eq. (11) gives the probability not worse than 0,95.

As a result, it has been stated that the value of the relation G/q discretely changes from particle to particle which is reflected in eq. (11). As the electric charge of the particles is a random value, this correlation must be fulfilled at $q = e$ (electron charge). The smallest value of a magnetic charge will be at $n = 1$ and $q = e$, i.e. from eq. (11) a charge "quantum" has the value

$$g = \frac{1}{2}\alpha\frac{e}{3} \tag{12}$$

The structure of the latter formula is predefined by the desire to express experimental results through the same constants, which correspond to the Dirac quantization condition (1). The comparison of (12) and (1) shows that

$$g = \frac{1}{3} \cdot \alpha^2 \cdot g_D \tag{13}$$

i.e a charge "quantum", defined by us, is $\simeq \alpha^2$ time smaller than a magnetic charge of Dirac monopole. At the same time its numerical value, obtained in eq.(12), $g = 5,84.10^{-13}\mathrm{gauss\,cm}^2$ is in a good agreement with evaluations of Ehrenhaft, Ferber [6] and Shedling [7] made before.

Experimental value of the relation of a number of the particle magnetic charges of opposite signs, determined in this experiment, is equal to $1,00 \pm 0,04$.

6. Observation of a recharging effect

In a homogeneous magnetic field a particle, carrying a magnetic charge $G = n \cdot g$, and moving with constant velocity, during a time t covers the distance

$$l = \frac{g \cdot H \cdot t \cdot n}{K} \tag{14}$$

where $K = 6\pi\eta r$ is a friction coefficient, η is gas viscosity, r is the particle radius.

Let us assume that in the process of movement the particle undergoes recharging and that $l_1, l_2, \ldots, l_i, \ldots, l_m$ are the lengths of a distance it passes, possessing the charges (in the units g) $n_1, n_2, \ldots, n_i, \ldots, n_m$, respectively. If these lengths are covered during equal time intervals τ, then there takes place a correlation

$$l_1 : l_2 : \ldots l_i : \ldots l_m = n_1 : n_2 : \ldots n_i : \ldots n_m \tag{15}$$

Thus, if a particle undergoes recharging, then the lengths of its trajectory, covered during equal time intervals, must apply among themselves as whole numbers. This assertion is correct for g of any value.

Among the particles, demonstrating the magnetic charge phenomenon (in this experiment the number of such particles is equal to 1887 [15]) we have found the particles, which have undergone recharging. The majority of particles undergo recharging at the moment of stopping, at changing of magnetic field direction (Fig.7).

These cases are particularly interesting because time interval reading is strongly simplified here. From this group we have chosen the particles, which on the observable length of the trajectory show not less than three recharging. Thus, for further processing, we have used photographs of trajectories of 114 particles.

For each particle we have built a row of ratios of trajectory isochrounous lengths. This row later was approximated with a correlation the members of which had the values close to whole numbers. For example for a concrete particle trajectory, shown in Fig.7, the relation of variable lenths of a trajectory (in 10^{-2}cm) has the form 0,88:1,67:1,67:0,88:3,43. Approximative relation in this case is 1,04:1,98:1,98:1,04:3,91 (which practically coincides with a whole-numbered row 1:2:2:1:4).

Fig.8 presents a histogram of charges distribution according to their value in g units : in abscissa experimentally obtained values n are shown, which are approximated to 1/10, in ordinates - a number of cases corresponding to the given n. The value g may be anyone, but on the basis of eq.(12) we think that it is the same for all the particles. Thus the spectrum in Fig.8 represents a frequency of a charge appearence divisible by g.

As is seen from the histogram, the spectrum of registered charges is a series of well solved equidistance lines, the distances between which correspond to the charge changing by a unit, and the width is conditioned by error definition

n_i (15), which comprises not more than 10% . This result fully agrees with eq.(15) and in this respect confirms the correctness of the initial supposition: formally the magnetic field interacts with the particle as with an object, carrying a magnetic charge.

Obtained experimental values n_i have been used by us for determining the diameter D of the particles, which take part in the observable phenomenon. From (14) it follows that for the j-th particle

$$D_{ji} = \frac{n_i}{l_i} \frac{gH\tau}{3\pi\eta} \tag{16}$$

A diameter for every particle we found as an average on m measurements:

$$D_j = \frac{1}{m} \sum_{i=1}^{m} D_{ji} \tag{17}$$

where m is the number of isochronous lengths of a trajectory.

Particle distribution according to the diameters, which has been built on the basis of calculation over (16) and (17) is regarded as an adequate distribution, obtained with direct measurements of particle diameters by an electronic microscopy method (Fig.4). Matching of the calculated histogram (Fig.4-a) with distribution based on the results of measurement (Fig.4-b), can be reached by varying the value g, since all the other members of eq.(16) in experimental conditions are strictly fixed: H=165 oe, $\tau = 1/14$ s, $\eta = 2\,10^{-4}$ poise. For these conditions the histogram alignment takes place at $g = 2,14.10^{-13}$ gauss cm^2. This value is of the same order as the value of the charge "quantum" (12) defined in [13,14], i.e. it coincides with the result, obtained by another method in an independent experiment.

7. Particle interaction with a linear conductor current field

A particle of a submicron size, forming at ferromagnetic dusting in an argon atmosphere due to spontaneous magnetization can possess a non zero magnetic moment $\vec{P}$. At a dipole interaction with a magnetic field $\vec{H}$ of linear current $\vec{I}$ the following force will influence such a particle

$$\vec{F}_d = \frac{2}{cR^2} \left[\vec{I} \wedge \vec{P} \right] \tag{18}$$

The force direction at a given $\vec{I}$ will be defined by a space position of vector $\vec{P}$.

As is known, the intensity of a magnetic field conductor of an infinite length is

$$\vec{H} = \frac{2}{c \cdot R^2} \left[\vec{I} \wedge \vec{R} \right] \tag{19}$$

Evidently, a free particle magnetic moment will be oriented in the direction of a intensity vector $\vec{H}$ and, thus the force $\vec{F}_d$ will be directed over the radius $\vec{R}$ to the conductor axis. As the particle moves in a gas, obeying the Stoke's law, its transference occurs with constant velocity, the direction of which at any moment of time coincides with an external force direction. So, the particles, possessing the magnetic moment, in a linear constant current field must transfer over a radius from the periphery to the conductor axis.

It is not difficult to be convinced that field interaction with high order multifields will cause radial movement of particles. Alongwith, as is known, the force of interaction decreases according to the law $1/R^{1+n}$, where n is a multipole order, and so the contribution of the members with $n > 1$ is insufficient.

It is worth noting that the described picture in no way depends upon the fact whether the particles are in the light field or not.

However basing on previous experiments we came to the conclusion that in the light beam the behaviour of some particles formally can be described by introducing magnetic charge $\pm G$. These particles in a linear conductor current field must be influenced by the force

$$\vec{F}_M = \pm \frac{2G}{cR^2} \left[\vec{I} \wedge \vec{R} \right] \tag{20}$$

and the particle trajectory must coincide with an arc of the radius circle R. From the particle motion equation

$$M \frac{d^2 \vec{R}}{dt^2} + K \frac{d\vec{R}}{dt} = \frac{2G}{cR^2} \left[\vec{I} \wedge \vec{R} \right] \tag{21}$$

we find for the established regime (for a spherical particle of radius $r \simeq 10^{-6}$ cm, relation $k/M \simeq 1/r^2 \gg 1$):

$$\omega = \frac{2 \cdot G \cdot I}{K \cdot c \cdot R^2} \quad , \quad R = \text{const.} \tag{22}$$

It means that the particle must move with an angular velocity ω over the circle with a constant radius R. Here M is the particle mass, $\vec{R}$ is the radius vector beginning at the current axis.

The character of particle interaction with a conductor field was investigated by us experimentally [16]. The experiment was performed on the installation, shown in Fig.1. In this case a part of the conductor 3 cm long and $5 \cdot 10^{-2}$ cm in diameter (Fig.9) serves as a field source. Current I, flowing in the conductor l, perpendicular to the scheme plane, generates the magnetic field $\vec{H}$. Aerosols'particles together with gas are injected into the volume near the conductor. Perpendicular to the conductor axis at a distance of 1 mm there passes a light beam the cross-section of which is marked in the figure by the contours 2. To prevent conventional fluxes in a gas, occurring at the conductor warming up by a current the observed region is isolated from the conductor by a thermoscreen 3-4.

In the same figure the trajectories of 12 particles are shown which move over the lines of the magnetic field at the current in the conductor I=10 A. (A summarized sample by the three independent microphotos, obtained by an exposure for several seconds). The tracks coordinates are measured with the aid of optical microscope with 50 times magnification. The size of the point in the figure characterizes the error of measurements.

The observed length of the particle trajectory is determined by the period of its being in a focal plane, from which the particle is led out by the brownian motion. Visual observations have shown that the number of cases of the particle movement clockwise and counterclockwise is equal at any current direction in the conductor.

As follows from the results of the experiments, the movement of these particles in the magnetic field is well described by the equations of the form (21), i.e. the interaction of the observed objects with a magnetic field has a pure monopole character (interaction of 1-power).

At steady-state particle motion in viscous medium its velocity is equal to (see, for example [8]) $v = F/k$. Then we get for radial and transversal velocity components

$$v_R = \frac{dR}{dt} = \frac{F_d}{K} \quad ; \quad v_t = R\frac{d\varphi}{dt} = \frac{F_m}{K} \tag{23}$$

Substituting the values from (18) and (20) and taking time integral we find

$$R^3 - R_0^3 = \frac{6 \cdot P \cdot I \cdot t}{c \cdot k} \tag{24}$$

$$\varphi - \varphi_0 = \frac{G}{P}\left\{\left[\frac{6 \cdot P \cdot I \cdot t}{c \cdot k} + R_0^3\right]^{1/3} - R_0\right\} \tag{25}$$

where R_0 and φ_0 are the initial coordinates at t=0.

From the latter, taking into account the equation (24) we obtain

$$\frac{G}{P} = \frac{\Delta\varphi}{\Delta R} \tag{26}$$

where:$\Delta\varphi = \varphi - \varphi_0$,$\Delta R = R - R_0$.

The particle magnetic moment determined from (24) is :

$$P = \frac{c \cdot k}{6 \cdot I \cdot t}(R^3 - R_0^3) \tag{27}$$

However the same magnetic moment of a particle can be expressed by its matter magnetic induction B and radius r (for spherical objects) :

$$P = \frac{1}{3}Br^3 \tag{28}$$

Substituting this value into (27) we get the formula for particle size determination

$$r = \left[\frac{3 \cdot \pi \cdot c \cdot \eta}{B \cdot I \cdot t}(R^3 - R_0^3)\right]^{\frac{1}{3}} \tag{29}$$

where R corresponds to t.

Thus, considering that particle is homogeneously magnetized up to the induction magnitude B, we get three formulas for the determination of its parameters r, P and G at the particle motion in the axial magnetic field :

$$\begin{cases} r = \left[\dfrac{3 \cdot \pi \cdot c \cdot \eta}{B \cdot I \cdot t}(R^3 - R_0^3)\right]^{1/3} \\ P = B \cdot r^3/3 \\ G = P\dfrac{\Delta\varphi}{\Delta R} \end{cases} \tag{30}$$

Thus , from this experiment it follows that the tangential component of the force, influencing the particle from the part of a magnetic field at an intensive lighting, is identical to the force, which would arise in the case of interaction of the magnetic monopole with a field and that the phenomenon observed may be caused by magnetic monopoles forming in the presence of light flux coupled systems with aerosol particles of ferromagnetics with any chance G–P relation.

The determination of the particle radial shift R is very difficult because of the negligible magnitude of the effect at its single passing through time-independent current conductor field. So, we modernized the experiment, using the scanning magnetic field of current which is the rightangle periodic pulses with alterating sign (the pulse duration is 0,25 s, the period of switching is 2 Hz, the amplitude is 6 A).

The photography of the magnetic aerosol particle tracks in such kind of field is given in Fig.9-b. It is clearly seen that quantitative characteristics of the various particles differ, but the motion pattern of any particle is determined by two factors: monotonous (independent of the field sign) motion to the axis of a conductor v_r and the oscillations in the plane, normal to the current vector, having a character of a periodic motion along the magnetic line of force v_t .

Our attempts to find the possible correlation between G and P for the particles ensemble (total number of particles is $\simeq 10^3$) have not led to detection of any rigid dependences. The distribution of particles in ratio of $G/P = \Delta\varphi/\Delta R$ has been the form, reminiscent of lognormal. The radiuses of the particles, calculated by (29) are in interval $10^{-5} \sim 10^{-6}$ cm , as expected. The value of G/P has a random character; the particles with the same moments, as a rule, have the different charges. The impression is gained that G and P are independent of each other quantities.

8. Discussions

The revealed quantitative characteristics allow to make some supposition about a possible mechanism of the charge forming on the ferromagnetic aerosols. Further considerations are based on the hypothesis according to which a photon passing near atomic nucleus induced the photoproduction of the monopole-antimonopole pair. The further future of this pair depends on the concrete physical conditions, in particular, on the presence of the magnetic field in the point of its generation.

In our case the pair photoproduction proceeds on ferromagnetic particle being magnetized either spontaneously or by action of the external magnetic field H. As a result of interaction with the magnetic field monopole and antimonopole are spatially divided after production and the probability of their annihilation becomes negligibly small.

On the particle surface the process of monopole separation by their sign occurs. This process is most pronounced on the magnetic poles. The monopoles with the charge the sign of which is the same as that of the pole are thrown off and the monopoles of opposite charge are confined and by the action of the internal magnetic field they migrate through the particle to another magnetic pole where they also leave its surface. Thus, two monopole currents with opposite charges moving in the direction of each other arise in the particle. If the total number of monopoles and antimonopoles producing these current is not balanced, the particle acquires non-compensated magnetic charge G.

To determine the value of this charge one should solve the system of diffusion equations together with the continuity equation and the Poisson's equation. It is rather difficult to solve this problem in general form. But to understand the physical sense of the effect considered the problem can be essentially simplified by reducing it to the one-dimensional problem since in the case considered the direction of the particle magnetic axis with respect to the light flux is fixed by the internal magnetic field and therefore the charge transport only along this direction is significant. Then when $H = H_x$, $H_y = H_z = 0$ the initial equations can be written as

$$\begin{cases} \dfrac{\partial}{\partial x}(\Delta n) + \dfrac{g \cdot B}{K \cdot T}(\Delta n) = \dfrac{I}{S \cdot D} \\ \dfrac{1}{g}\dfrac{\partial G}{\partial t} = \Phi \cdot \sigma - I \\ \dfrac{\partial B}{\partial x} = 4 \cdot \pi \cdot g(\Delta n) \end{cases} \tag{31}$$

Here g is the monopole charge, $\Delta n(\mathrm{cm}^{-3}) = n^+ - n^-$ is the difference of the opposite charge monopole concentrations, $I(\mathrm{s}^{-1})$ is resulting monopole current in the particle, $\Phi(\mathrm{cm}^{-2} \cdot \mathrm{s}^{-1})$ is the photon flux density, S is the particle cross-section perpendicular to the current I . Diffusion coefficients D are considered to be equal for monopoles and antimonopoles. σ is the difference of the integral cross-sections for pair generations between the regions of particle surface adjacent to its different poles. The magnitude and the sign of σ depends on the extend of surface inhomogenity and the difference in the concentration centres of pair generation. $B = \mu \cdot H$ is the magnetic inductance of the particle matter.

In the stationary case $\partial G/\partial t = 0$ and the current I proportional to the light flux will pass through the particle $I = \sigma \cdot \Phi$.

A particle of any regular form can be represented as a set of coaxial cylinders. Therefore, condition $S =$ const. seems to give a sufficiently correct estimate of the charge value. Moreover Δn can not be large (this is confirmed by the experiment) therefore one may consider B as a constant along the whole length of the particle 1 . Then from the condition that if $B = 0$, $\Delta n = 0$ (this naturally follows from the assumption that without magnetic field the act of pair production is immediately followed by its annihilation) the solution of the diffusion equation in the system (31) can be written as

$$\Delta n = \frac{I}{D \cdot S} \cdot \frac{K \cdot T}{g \cdot B} \left[1 - \exp(-\frac{g \cdot B \cdot x}{k \cdot T}) \right] \tag{32}$$

The magnetic charge of the bulk element $dV = Sdx$ is determined by the expression $dG = g \cdot \Delta n \cdot S \cdot dx$ and the total magnetic charge of the particle is

$$G = \frac{I}{D} \frac{kT}{B} l \left\{ 1 - \frac{kT}{gBl} \big(1 - \exp(-\frac{gBl}{kT})\big) \right\} \tag{33}$$

where l is the particle size.

In virtue of stationarity this charge is localized at any moment of time in the particle volume and it interacts with its internal magnetic field $H_i = 4\pi P = B - H = H(\mu - 1)$ with force $F = G \cdot H_i$. On the other hand the monopole current interacts with conduction electrons due to electromagnetic inductance. If the particle moves in gas as in viscous matter according to Stokes'law then having confined by the phenomenological approach, one can equate the force F to the effective friction force. Then the particle velocity is

$$v = \frac{G \cdot H \cdot (\mu - 1)}{3\pi\eta l} \tag{34}$$

where η is the effective viscosity coefficient accounting for the resistance of the matter and the mutual "friction" of the monopole current and the particle lattice, μ is the magnetic permeability of the particle matter.

Thus, from eq. (33, 34) it follows

$$v = a\Phi \frac{\mu - 1}{\mu} \left\{ 1 - \frac{T}{b \cdot H} \left[1 - \exp(-\frac{b \cdot H}{T}) \right] \right\} \tag{35}$$

where

$$a = \frac{\sigma KT}{3D\pi\eta} \quad \text{and} \quad b = \frac{g\mu l}{K}$$

are constant values for the given particle (does not depend on temperature since $D \simeq T/\eta$).

Equation (35) is , thus, a logical consequence of the working hypothesis accepted by us and it can be verified experimentally.

The extremal values from eq. (35) are :

a. H =const. If $\Phi \to 0$, then $v \to 0$; if $\Phi \to \infty$, then $v \to \infty$.

b. Φ =const. If $H \to 0$, then $v \to 0$; if $H \to \infty$, then $v \to a\Phi\frac{\mu-1}{\mu}$ (the effect of "saturation" [9]).

c. H = const. Φ = const. If $\mu \to 1$, then $v \to 0$.

Comparing eq. (35) with the experiment we can mark out the following facts:

1. The dependence $v(\mu)$ points out that the effect considered can be observed only for ferromagnetics when $(\mu - 1)/\mu \to 1$. For paramagnetics and diamagnetics when $| \mu - 1 | \simeq 10^{-6}$ the velocity v becomes much smaller than that of Brownian motion and in the experiments like this one [14] it is impossible to measure the velocity since the effect is beyond the sensitivity of the method. Thus, the connection of this effect with ferromagnetism becomes clear.

2. We and Ehrenhaft [9] experimentally investigated the dependence of the particle velocity on the magnetic field strength. The character of the dependence obtained in our experiment for the mean particle velocity in the ensemble [8] is similar to that obtained for individual particle in [9]. In Fig.10 the dependence $v(H)$, Φ =const. (points) taken from [9] is shown for particle N 28 – comparison of our calculations with the results of the other author seems to be more conclusive for us. The velocity calculated by (35) is also plotted in this figure as a function of H (solid curve). Obviously, the agreement of the calculated and experimental result is satisfactory. It should be noted that the character of particle velocity dependence upon the magnetic field strength is not trivial. The effect of velocity "saturation" at fields with the value of H more than 5 oersted had no reasonable explanation thus far. In the framework of our calculations this effect has got its natural interpretation, it may be considered as a consequence of the total particle charge decrease when the external magnetic field H increases, this unambiguously follows from the expression (33).

3. The dependence of particle velocity on the light flux intensity Φ at fixed values of H has been investigated by the author in [8]. The results obtained are presented in Fig.10 as experimental points each of them is provided by the measurements of not less than the velocity of 300 particles. Comparison of the calculated curve (35) (solid line) with the experimental values of the mean particle velocity in the ensemble reveales complete agreement.

However, inspite of a good agreement of the calculated results with the experimental data there is an uncertainty in the rightfulness of selected initial preconditions. In connection with it we want to show the facts which make the problem some clear (though it generates new vaguenesses).

We run into a phenomenon, unknown earlier and misunderstandable during the investigation of the behaviour of the aerosol electric charged particles in homogeneous electric field (the same as in the previous experiments). It is unknown because there are no words about it in the classical electron charge measurements of Millikan et al. (later, we have discovered , that in the work [18] Ehrenhaft mentioned about the similar observation). It is incomprehensible because the well-known regularities of photoeffect on the massive body surface can not explain this fact.

The question is that the change of the particle velocity in dependence of the electric field E and magnitude of light flux Φ submits to the same regularities which have been established earlier for magnetic variant. What is said above is illustrated graphically in Fig.10. The linear growth of the velocity with an increase of flux Φ and vice versa, the effect of "saturation" at increasing the strength E are rather unexpected. Indeed, in the first case the conclusion suggests itself that the particle electric charge increases proportional to the flux of photons. But the energy of photons in our experiments is far away over the red photoelectric threshold (in this case we use light with wavelength $\lambda = 4880$Å, that is $h\nu = 2,54$, whereas work function is $\gg$4 eV) ! . The effect of the "saturation" velocity at increasing E suggests an idea about a loss of charge at the large values of the field strength (Schottky effect, autoelectronic emission). In any case these are surmises and detected regularities need in future serious investigation. But this phenomenon does away with the distinctions between the conductor of ferromagnetic particles in the magnetic and electric fields (in the conditions of intensive illumination): observing the particle motion in the conditions of our experiments it is impossible to say anything apriori about the kind of the field in which they are moving.

Thus, we come to the extremely potent logical conclusion: the nature laws lying in the basis of the detected effect are the same. Or it is the interaction of field E and H with electric and magnetic charges correspondingly, or (if negating the magnetic charge) we are forced to cast doubt on the reality of the electric charge (that is difficult to agree with not waiving the common sense).

Our investigations show that the phenomenon under consideration is not a rare and hardly reproducible event. On the contrary, the number of the pointed out cases of ferromagnetic particle behaviour as the objects with a magnetic charge in the conditions, described above, is sufficiently large. There arises a natural question: why the presence of these charges has not been found by other experiments until now ? The answer to this question becomes clear when analysing the properties of the observed objects. The estimations show that monopoles detection with a charge $g \ll e$ by traditional methods (ionized losses of energy, Cherenkov radiation, superconducting quantum interferometer etc.) is either connected with technical difficulties, or is impossible. It suggest an idea that a casual magnetic monopoles discovery possessing such properties is hardly probable. It is possible that the proposed by us method which allows to measure the forces of the order of 10^{-10} dynes is, to some extent, unique.

The investigation of the effect described in this review is greatly complicated by the absence of theoretical researches in this field of the phenomena. It has seemed to be natural because the modern microcosm physics does "not need" such a monopole. However some works which can help, to this or that extent, to understand the discussed question are known to the author. So in Lubomudrov's work [19] in which, taking into account the Dirac theory initial statements and the principle of complementarity, Maxwell's equations are generalized to the case with a magnetic charge, it is concluded that the monopole magnetic charge magnitude cannot principally be expressed through the electric one and should be found experimentally. For all this the monopole mass must be negligible.

Wang Li, working within the frames of the Einstein Kaufman unified field [20] and analysing the work [14] states that a monopole with the charge much less than that of Dirac can be an attribute of an electron itself.

The ideas, developed in G. Lochak works [21,22] in application to our experimental results seem to be greatly fruitful. Zero or negligible monopole mass and the absence of the charge antiparticles (couples) takes away limits on the monopole parameters, conditoned by magnitude of the muon anormal magnetic moment [23] since a polarization of vacuum is excluded. Besides, a wide prevalence of our monopoles which we have in experience does not seem to be strange. At such approach to the problem, the distinction of the charge magnitude, which we have determined, from that of Dirac's monopole, one can try to explain by the fact that we observe the in time averaged value of some oscillating ("flicking") monopole, life time and the birth frequency of which are predetermined by the monopole parameters and the photon field characteristic correspondingly. If it is right, then the "flicking" Dirac monopole, interacting with the magnetic field of the installation can be perceived as a magnetic charge of much less magnitude.

However, all this to a considerable extent is a prerogative of theoretical physics and the success of explaining phenomenon observed substantially depends on the fact whether this paper will attract attention of theoretical physicists.

9. Conclusions

A series of performed experiments allow us to confirm the following:

1. A stable physical phenomenon is observed which up to till now doesn't have a generally accepted interpretation.
2. All the efforts to explain the phenomenon on the basis of the known physical phenomena don't lead to positive results.
3. The total sum of revealed regularities on the level of phenomenon organization which was available to our methodics is simply and uncontradictorily explained by a version with a participation of the superlight magnetic monopole of charge $g \simeq \alpha e$.

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RÉSUMÉ. On décrit des investigations expérimentales sur le comportement d'aérosols ferromagnétiques dans des champs magnétiques et électriques de différentes configurations. On a établi que nombre de particules d'aérosols soumises à une illumination intense se déplacent dans le champ magnétique comme des objets portant une charge magnétique.

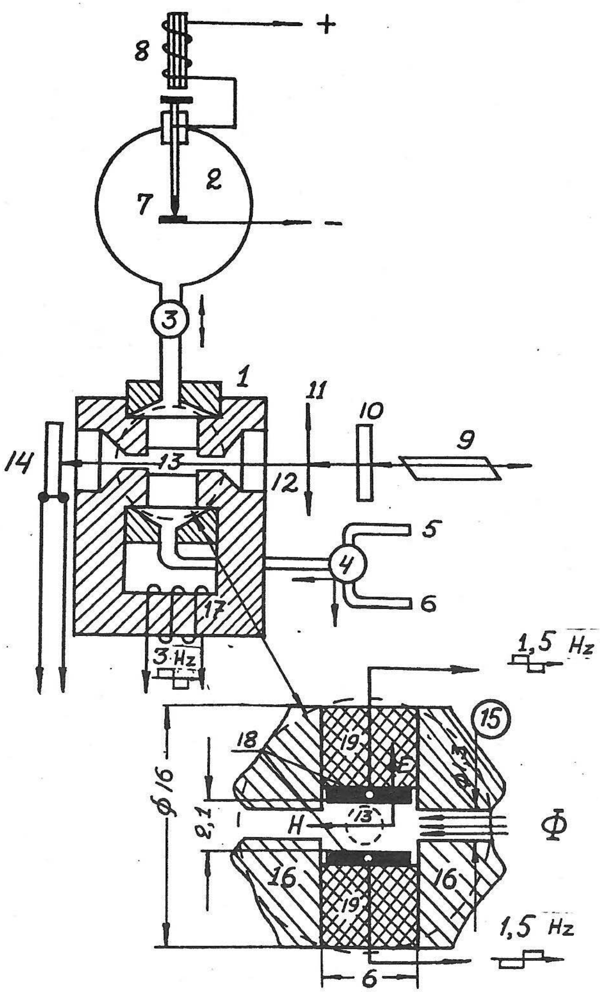

Figure 1. Experimental apparatus.

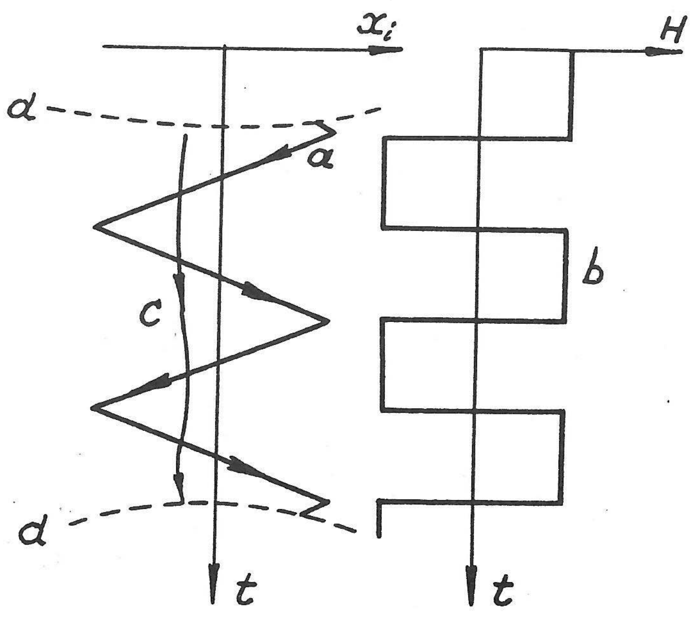

Figure 2. Magneto-sensitive particle trajectory (a) in a magnetic field changing at the law (b); (c) particle trajectory insensitive to a magnetic field; (d–d) the light beam contour. Particles transfer in a vertical direction due to a gas slow blowing off (for a trajectory scanning at time).

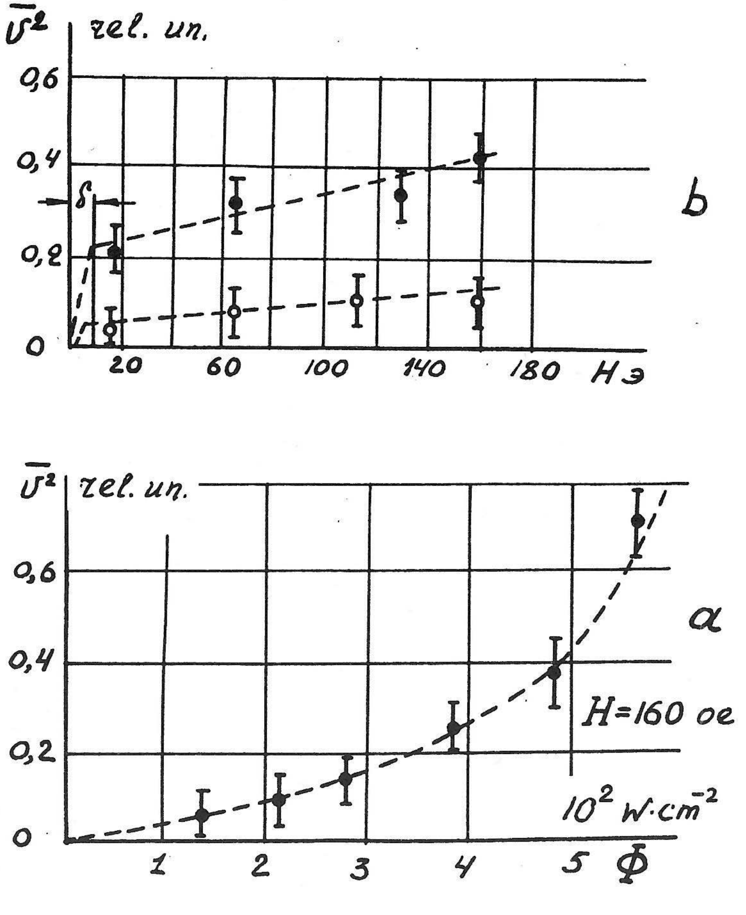

Figure 3. Dependence of a mean-quadratic particle velocity in an ensemble upon the light flux power Φ – (a) and the value of the magnetic field intensity H – (b) .

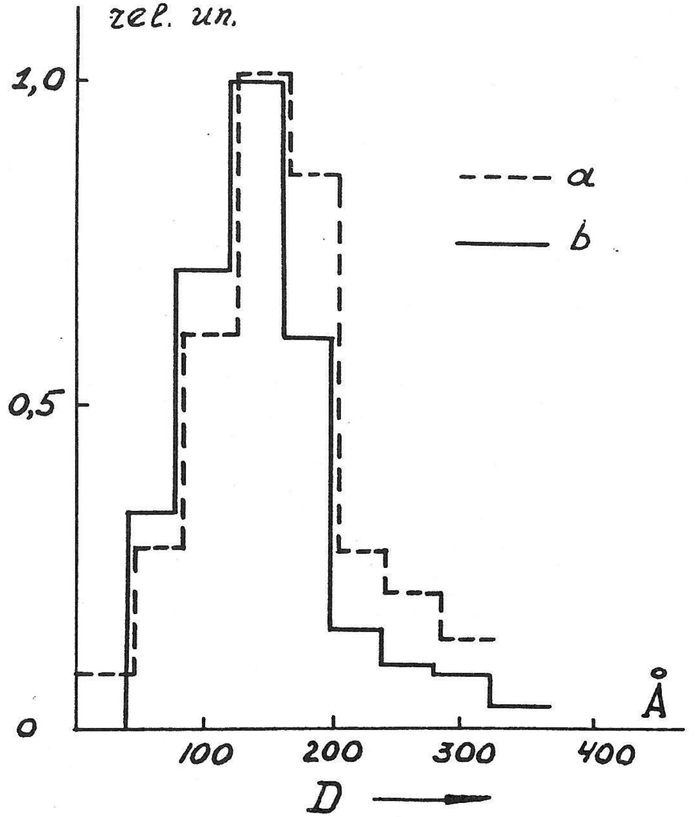

Figure 4. Histograms of particles distribution according to the diameter: (a) drawn in accordance with the results of eqs.(16) and (17), (b) drawn in accordance with the results of measurements.

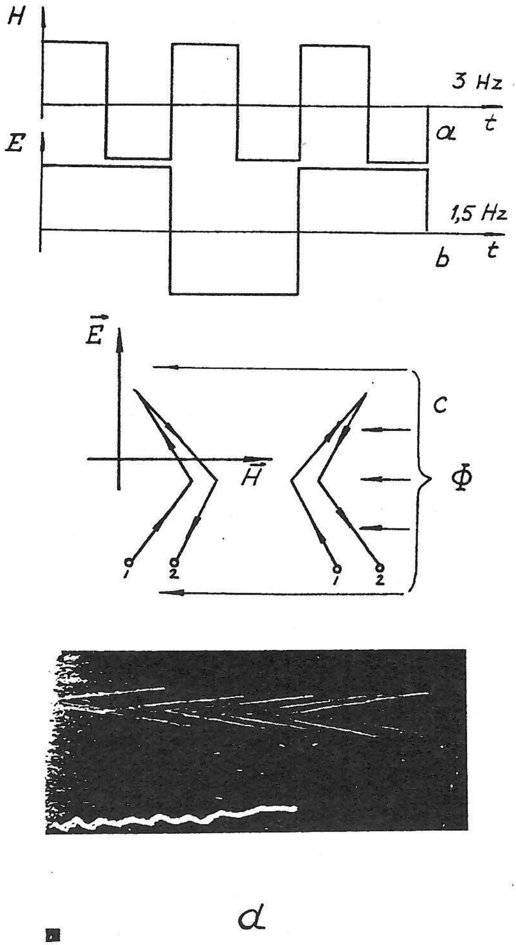

Figure 5. Temporal field diagrams H – (a), and E – (b), and particles trajectories for a single electric field period; (c) – is the scheme of two particles trajectories with magnetic charges of the opposite signs; (d) – is a photograph of a track of a binary charged particle (at the bottom the particle's track carrying the electric charge only (not in a focus).

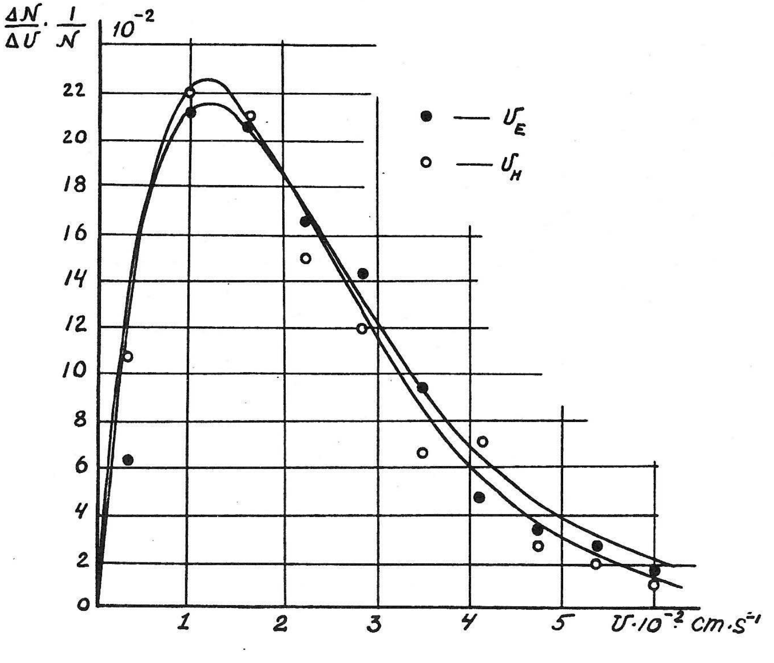

Figure 6. Distribution of particles by the velocities v_E and v_H in the electric and the magnetic fields.

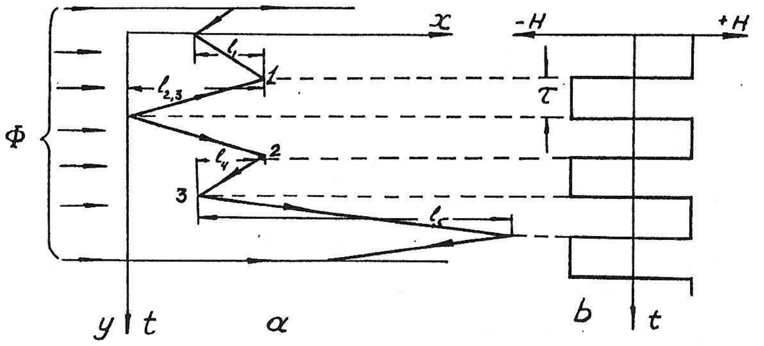

Figure 7. a) Trajectory of a particle undergoes three rechargings in a homogeneous magnetic field. The particle fluctuates synchronously with the field along its field lines in parallels with the axis X. Trajectory scanning by the Y axis is done on the account of the particle shift by the gas flux. The points 1, 2, and 3 correspond to the recharging moments $l_1 = l_4 = 0,68 \times 10^{-2}$cm ,$l_2 = l_3 = 1,67 \times 10^{-2}$ cm. Φ is a light beam. b) The temporal diagram of the magnetic field intensity H =165 Oe, the half-life $\tau = \frac{1}{14}$ s .

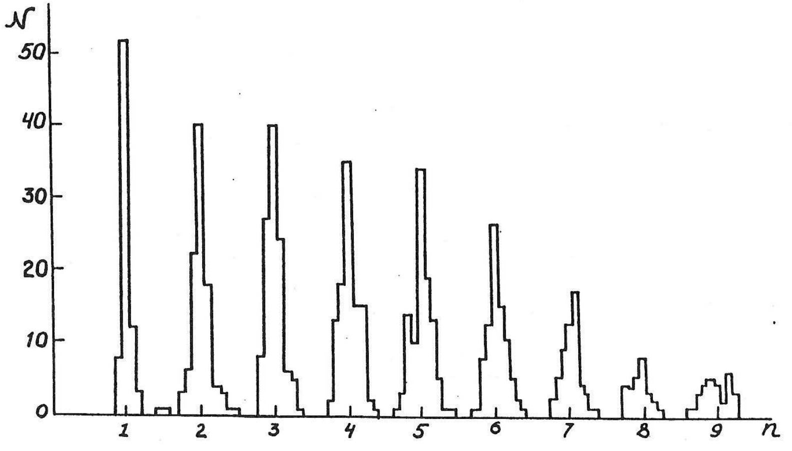

Figure 8. Magnetic charges spectrum. N is a full number of registered charges for 114 particles.

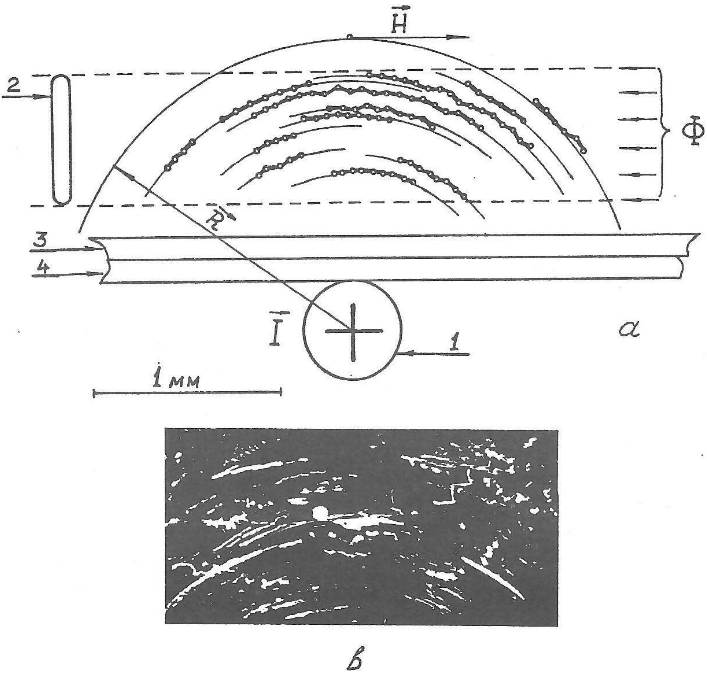

Figure 9. a) Reconstruction of the particle trajectories in a current linear conductor magnetic field : (1) the current conductor perpendicular to the scheme axis; (2) the light beam crossing; (3,4) the thermal screen: (3) copper, (4) glass. b) The photograph of the particles tracks with a magnetic charge in the magnetic field variable with the time.

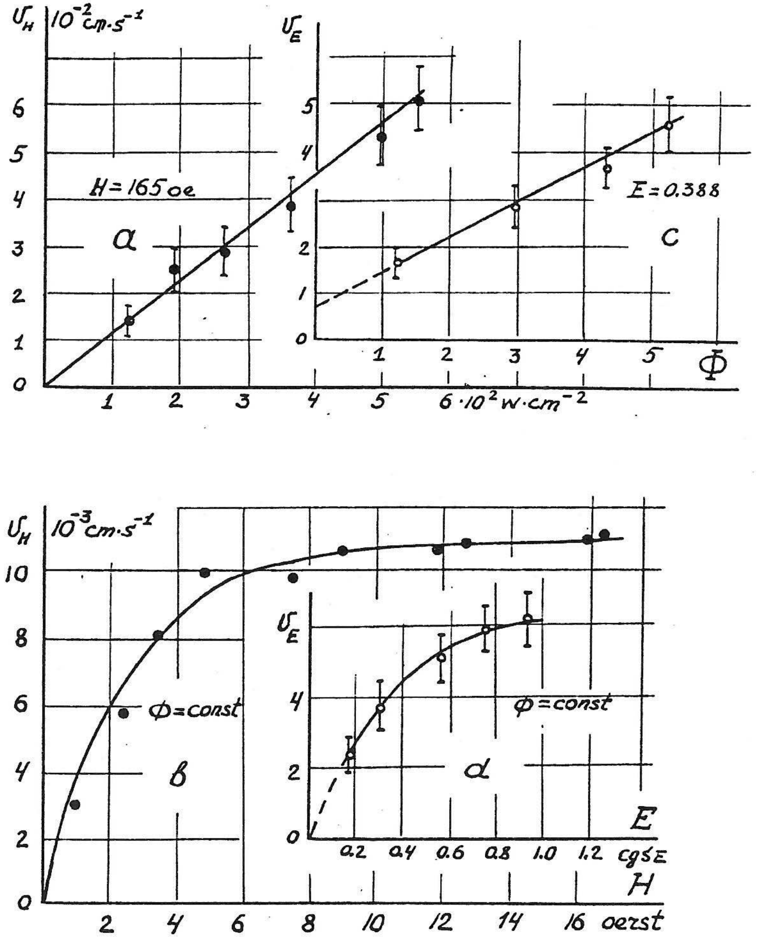

Figure 10. Dependence of particle velocity upon: a) the light flux intensities [8]; b) magnetic field intensity (particle N 28 [9]): $g = 5,84 \times 10^{-}13\text{G.cm}^2$, $l = 1,73 \times 10^{-}5$ cm,$\mu = 3600, T = 283\text{K}, \Phi = \text{const}$. (c,d) the same for electric charged particle in the electric field.