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1990 J. Phys. A: Math. Gen. 23 53

(http://iopscience.iop.org/0305-4470/23/1/012)

J. Phys. A: Math. Gen. **23** (1990) 53-63. Printed in the UK

On some regularities of aerosol particle motion in electromagnetic fields

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Received 30 September 1988, in final form 20 April 1989

Abstract. The paper is devoted to the results of experiments studying aerosol behaviour in magnetic and electric fields of various configurations. A complete analogy with the behaviour of ferromagnetic particles in uniform magnetic and electric fields is presented. Possible mechanisms of movement of the ferromagnetic particles in the constant magnetic field and the validity of a model with a magnetic charge are discussed.

1. Introduction

This paper is the extension of previously published works (Mikhailov 1983, 1985, 1987) on the study of the following effect: when subjected to a high-intensity light beam some ferromagnetic aerosol particles move in the magnetic field along its lines of force; the reversal of the field vector $\boldsymbol{H}$ causes the reversal of the particle motion; motion ceases when the field is switched off. An increase or decrease of field strength or luminous flux intensity causes the particle velocity to increase or decrease, respectively. The number of particles, moving in the direction of $\boldsymbol{H}$, up to measurement error, equals the number of particles moving in the opposite direction.

In other words, the behaviour of the experimental particles is similar to that of objects carrying magnetic charges with opposite signs.

The experimental procedure apparatus (the prototype of which was used by Millikan for measuring electron charge) has been described in our earlier publications (Mikhailov 1983, 1987).

In studying the effect we have processed the paths of about 4000 particles. The characteristics of the effect are given in figure 1 as two sets: (a) $v = v(\Phi)$, for constant H and (*b*) $v = v(H)$ for constant Φ, where v is the particle velocity and H is the magnetic field strength and Φ is the luminous flux intensity (Mikhailov 1987).

What is the physical basis of the phenomenon observed? What is the mechanism of energy conversion in the kinetic energy of a particle? What is the source of its motion? These are the main questions which must be answered to explain the nature of the effect.

2. Radiometric model

Suppose that a particle moves at the expense of the energy it gets from a beam of light. Within the frame of purely energic relations, this looks as follows.

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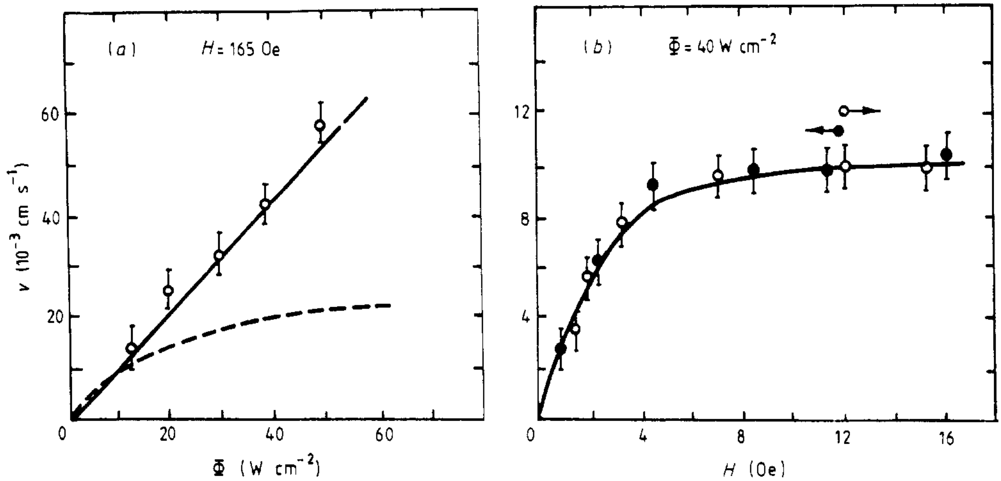

Figure 1. Characteristics of the photomagnetic effect on the ferromagnetic aerosol particles in the uniform magnetic field, plotting the particle velocity v as a function of (a) luminous flux intensity and (*b*) magnetic field strength (for particle radius 10^{-6} cm and light wavelength $\lambda = 6328$ Å). The broken line in (*a*) is $v = \sqrt{\Phi}$.

For motion in a viscous medium with friction coefficient $K = 6\pi\eta r$ (assuming the particle to be spherical, with radius r) the power dissipated due to friction is

$$P_f = Kv^2 \tag{1}$$

(η is the gas viscosity factor). Other losses (thermal conductivity of gas radiation, etc) will be designated as P_{dis}. Then the power balance is written as:

$$Kv^2 + P_{dis} = \sigma\Phi \tag{2}$$

where σ is the light-absorption cross section. Since $P_{dis} = a\Phi^n$, where $n \geqslant 1$, then it follows that

$$v \sim \sqrt{\Phi}. \tag{3}$$

However, the experimental relationship (figure 1(*a*)) is actually

$$v \sim \Phi. \tag{4}$$

Thus we conclude that the initial premises are wrong—particle motion is not defined by the energy contribution of a beam of light, i.e. the effect may not be classified as radiometric. (Note that in the disturbance of the Stokes nature of motion, the discrepancy between experiment and theory will be even greater because the latter, when turbulence occurs, entails the relationship in the form $v \sim \Phi^{1/n}$, where $n > 2$).

The failure of a radiometric model may also be displayed as follows. First, there is the absence of correlation between the light-beam direction and the velocity of particle motion: independent of the angle between the field vector $\boldsymbol{H}$ and the light-beam axis, the particle velocity is invariably collinear with vector $\boldsymbol{H}$. But suppose there were a more complex mechanism: due to heterogeneity of particle surface and as a result of the accommodation factor ambiguity at various sites, pressure unbalance occurs under the particle–gas temperature jump ΔT and there is a resultant force $\boldsymbol{F}$ applied to the particle. The particle is magnetised spontaneously and has magnetic moment μ. In this case, in the uniform magnetic field the force $\boldsymbol{F}$ is determined finally only by the temperature difference ΔT.

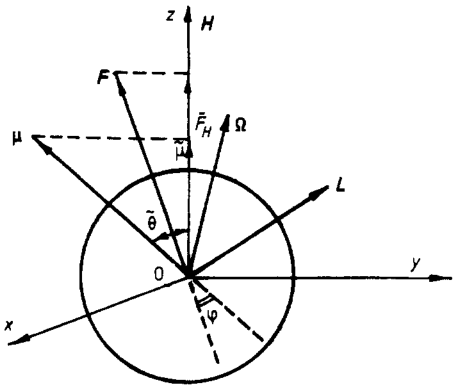

Figure 2. Dynamic diagram of the radiometric effect in the polarising field when the line of the external force F action does not coincide with the centre O of the particle mass ($\tilde{\mu} = \mu\ \widetilde{\cos}\ \theta$, $\tilde{F}_H = F\cos(\tilde{\theta} - \varphi)$).

Let the line of the F force action be tightly fixed relative to the magnetic moment $\boldsymbol{\mu}$ and the centre of the particle mass ((figure 2), i.e. the angle φ is constant. In this way, a particle in the magnetic field H is affected by the force F, by friction forces, the coupling reaction $(\boldsymbol{\mu}, \boldsymbol{H})$ and the torque L, which in general does not coincide with the instantaneous rotation axis Ω. This task is rather complex, though a roundabout way is outlined which allows us to make some judgement.

It is known that the time average of the magnetic moment projection of a particle like that to vector H is $\tilde{\mu} = \mu\ \widetilde{\cos}\ \theta$, where $\widetilde{\cos}\ \theta = L(\beta) \equiv \coth(\beta) - 1/\beta$ is the Langevin function ($\beta = \mu H/kT$). At a given β there exists a certain average angle $\tilde{\theta}$ and projection of the force F to the magnetic field vector may be represented (figure 2) as $\tilde{F}_H = F\cos(\tilde{\theta} - \varphi)$. One can easily see that, in a general case, with increasing H and decreasing $\tilde{\theta}$, the value of the projection $\tilde{F}_H$ can pass through the maximum and then diminish (and can even change to the opposite direction) and this will cause the situation when, as the field strength H increases, the particle velocity starts to decrease and its inversion is possible. Such facts are not observed in the range of fields which, at least by severalfold, exceed the critical values corresponding to 'the saturation' of the curve $v = v(H)$, $\Phi = \text{constant}$ (figure 1(b)).

Thus, in the light of the above, a radiometric model of the effect appears to be unsatisfactory.

3. Motion in electric and magnetic fields

As seen from figure 1(b), the particle velocity is not proportional to the magnetic field strength. At a value of H between 2 and 6 Oe the characteristic deviation (or velocity 'saturation') is observed. Proportionality would allow us to introduce a magnetic charge formally and thereby to clear up, to some extent, the problem of the energetics of the effect (since in this sense only a magnetic field may be the alternative of the flux Φ). Nevertheless, it is possible to develop a model with a variable magnetic charge (Mikhailov 1987) describing in an analytical way the experimental relationships $v = v(H)$, $\Phi = \text{constant}$ and $v = v(\Phi)$, $H = \text{constant}$. However, the initial prerequisites of this model may prove to be inadequate to this effect mechanism and therefore are not discussed here.

In the experiment it has been found that a great number of particles showing the effect of magnetic charge are also charged electrically. This gave us the idea to compare the forces acting simultaneously on such a 'dyon-particle' from the magnetic H and electric E fields, as published in Mikhailov (1983, 1987). However, we subsequently studied the relationships $v = v(E)$, $\Phi = \text{constant}$ and $v = v(\Phi)$, $E = \text{constant}$ and these are here published for the first time.

Figure 3 shows the results obtained with electrically charged particles of platinum, silver and magnetite (para-, dia-, ferromagnetic). The similarity of these curves to the relationship $v = v(H)$ (figure 1(b)) is evident. The difference of the absolute velocity values for various materials may be related to the difference of the charge and the degree of the dispersity. At the same time, liquids such as glycerine and oil (classical 'Millikan's substances') show no effect of saturation: the direct proportionality $v \sim E$ is evident (figure 3(b)). Perhaps the deviation from the linearity for solids is connected with the fact that the particle shapes differ from the spherical ones which leads to the disturbance of the Stokes nature of motion. However, the particle velocity $v \sim 10^{-2}$ cm s^{-1} and the Reynolds number $\mathrm{Re} = rv\rho/\eta \sim 10^{-6}$ for a spherical particle, having a radius 10^{-6} cm, remove all hope that such an approach may be fruitful. (Incidentally, we have studied the shape of magnetic particles which are close to spherical; however, on smaller particles with radius of the order of 10^{-6} cm, facets in the form of pentadodecahedrons are clearly seen (Mikhailov 1987).)

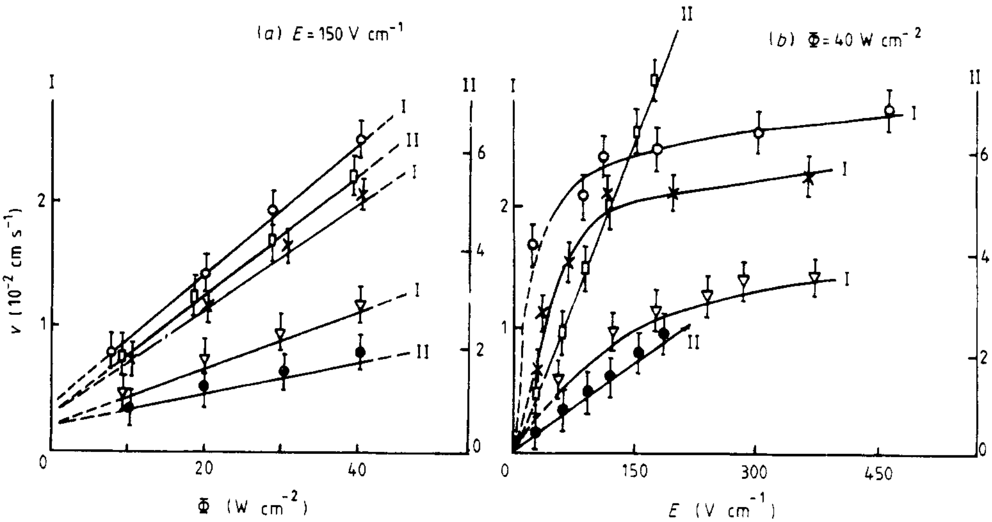

Figure 3. Dependence of particle velocity in the uniform electric field ($\lambda = 4400$ Å) on (a) intensity of luminous flux Φ at constant E (the particle velocity in an electric field is not zero at $\Phi = 0$ because the electric charge of a particle (unlike a magnetic one at $\Phi = 0$) is conserved), and on (b) strength of electric field E at constant Φ for Ag (○), Pt (×), Fe_3O_4 (▽), glycerine (□) and oil (●). The labels I and II refer to left- and right-hand scales respectively.

Nevertheless, this influences the process in both electric and magnetic fields in the same way: the character of the medium resistance is independent of the nature of forces applied to the particle. On these grounds we think it correct to compare those forces simultaneously affecting the particle from the electric and magnetic fields.

In the following experiment we used synchronously and spatially changing uniform fields, and as in Mikhailov (1983, 1987), vector $\boldsymbol{E}$ is perpendicular to vector $\boldsymbol{H}$ and both lie in the plane parallel to the focal plane of the microscope. The scheme of fields and particle trajectory under these conditions are shown in figure 4. It is seen from this figure that

$$\mathrm{d}l_E/\mathrm{d}l_H = a = \text{constant}. \tag{5}$$

But $\mathrm{d}l_E = v_E\,\mathrm{d}t$, $\mathrm{d}l_H = v_H\,\mathrm{d}t$, where v_E and v_H are particle velocity components in $\boldsymbol{E}$ and $\boldsymbol{H}$ directions, respectively.

Thus

$$v_E/v_H = a. \tag{6}$$

If u_E and u_H are mobilities, then

$$v_E = u_E F_E \qquad v_H = u_H F_H \tag{7}$$

or

$$v_E/v_H = u_E F_E/u_H F_H = a. \tag{8}$$

According to the Einstein relation, mobility is connected with the diffusivity D as follows:

$$u = D/KT \tag{9}$$

that is, mobility u is independent of the nature at the external force and at the given conditions is determined only by the properties of the particle and medium. So we write with good reason that $u_E = u_H$ and therefore

$$F_E = aF_H \qquad a = \text{constant}. \tag{10}$$

Note that formula (10) is valid at any time t if the strengths of fields E and H are proportional, i.e. if

$$H = bE \qquad b = \text{constant}. \tag{11}$$

This last condition is inherent in the experimental procedure.

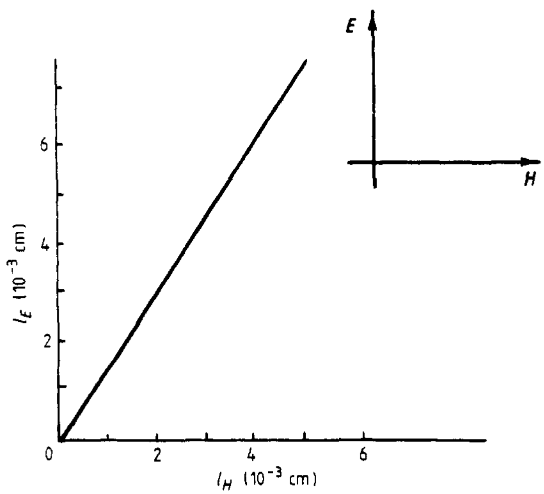

Figure 4. Path of the ferromagnetic dual-charged particle in crossed uniform synchronous electrical and magnetic fields: $E = E_0 \sin \omega t$, $H = H_0 \sin \omega t$, $E_0 = 250\ \mathrm{v/cm^{-1}}$, $H_0 = 15$ Oe, frequency $f = \omega/2\pi = 2$ Hz ($\lambda = 4400$ Å).

4. Magnetic charge

Since, according to the logic of section 2, we may not rank the effect among the radiometric ones and consider the particle's 'moving force' as the thermal one (and this logic is similarly applicable to the case of both magnetic and electric fields) then, at least in the electric field (when the charge existence itself is undoubted), we can write

$$F_E = qE \tag{12}$$

where q is the particle's electrical charge.

But then, according to (10)-(12), it follows inevitably that

$$F_H = qE/a = qH/ab. \tag{13}$$

where a, b and q are constants.

Denote $q/ab = g$. Then

$$F_H = gH \tag{14}$$

that is, F_H is proportional to H and the proportionality constant g has dimensionality of a charge. In other words, if $F_E = qE$, then $F_H = gH$, when g is magnetic charge.

This charge value can be readily defined by (6), (11) and (14):

$$g = q/ab = \frac{v_H}{v_E}\frac{E}{H} \tag{15}$$

or

$$g = q\frac{l_H}{l_E}\frac{E}{H}. \tag{16}$$

Since $q = ne$, where e is the electron charge and n is an integral number, then

$$g = ne\frac{l_H}{l_E}\frac{E}{H}. \tag{17}$$

Charge value determined in this experiment by formula (17) is of the same order ($\sim 10^{-11}$ Gaussian units) as the value previously obtained by Mikhailov (1983).

Thus, the effect has been observed consistently and its basic characteristics have been studied. The present situation is well summarised in table 1 which includes the main results we have obtained experimentally (Mikhailov 1983, 1985, 1987).

The complete analogy of particle behaviour in uniform magnetic and electric fields is traced quite unequivocally. When observing a particle under these conditions, it is impossible to determine in which field it moves without knowing this *a priori*.

Consider, in particlar, the experiment with the magnetic field of a line conductor with a current (figure 5) (Mikhailov 1985). In this field ferromagnetic particles move along a circular arc (along the line of force) and at the same time they displace to the conductor axis. The change of current direction induces the reversal of particle velocity. At the same time one can observe particles which move both clockwise and counter-clockwise.

The absence of a conductor carrying magnetic current does not allow us to perform the experiment with electrically charged particles which could enter symmetrically into

Table 1. Summary of observed particle motion, demonstrating its completely analogous behaviour in uniform electric and magnetic fields.

	Uniform electric field, E	Uniform magnetic field, H
1	At constant E the particle moves along the line of force with constant velocity. Reversal of the field $\boldsymbol{E}$ direction causes the reversal of the particle velocity, and field shut-down causes the particle to stop. On increasing E, the particle velocity, at constant Φ, rises non-linearly (the effect of velocity 'saturation' occurs). The relationship $v = v(E)$, at constant Φ is shown in figure 3(b). The number of particles moving along the sense of vector $\boldsymbol{E}$ and in the opposite direction is equal. The effect is observed at any angle between the light-beam axis and the sense of the installation $\boldsymbol{E}$ field strength vector.	At constant H the particle moves along the line of force with constant velocity. Reversal of the field $\boldsymbol{H}$ direction causes the reversal of the particle velocity, and field shut-down causes the particle to stop. On increasing H, the particle velocity, at constant Φ rises non-linearly (the effect of velocity 'saturation' occurs). The relationship $v = v(H)$, at constant Φ is shown in figure 1(b). The number of particles moving along the sense of vector $\boldsymbol{H}$ and in the opposite direction is equal. The effect is observed at any angle between the light-beam axis and the sense of the installation $\boldsymbol{H}$ field strength vector.
2	At constant E the particle velocity rises linearly with the increase of the luminous flux intensity Φ. The relationship $v = v(\Phi)$ is shown in figure 3(a).	At constant H the particle velocity rises linearly with the increase of the luminous flux intensity Φ. The relationship $v = v(\Phi)$ is shown in figure 1(a) (Mikhailov 1983, 1987).
3	The velocity of some particles, at constant E and constant Φ, changes unevenly. Cases of velocity reversal (recharging) have been observed.	The velocity of some particles, at constant H and constant Φ, changes unevenly. Cases of velocity reversal (recharging) have been observed (Mikhailov 1987).
4	For the case when $\boldsymbol{E}$ is vertical, the particle in the gravity field can be brought to equilibrium by changing the value of E. In this case E is single-valued at any point of the space. Cases are observed of the spontaneous disturbance of the equilibrium, which is restored at another value of the field strength E (recharging, classical experiment of Millikan).	For the case when $\boldsymbol{H}$ is vertical, the particle in gravity field can be brought to equilibrium by changing the value of H. In this case H is single-valued at any point of the space. Cases are observed of the spontaneous disturbance of the equilibrium, which is restored at another value of the field strength H (recharging, Ehrenhaft 1940, 1951).
5	At the constant intensity of light beam and constant E, the particle velocity rises with a decrease of the light wavelength (according to observations, $\lambda_1 = 4400$ Å, $\lambda_2 = 4480$ Å, $\lambda_3 = 6328$ Å).	At the constant intensity of light beam and constant H the particle velocity rises with a decrease of the light wavelength (according to observations, $\lambda_1 = 4400$ Å, $\lambda_2 = 4480$ Å, $\lambda_3 = 6328$ Å).

table 1. It has, however, been observed that, under very high magnification, the photographic tracks of some particles present a wavy line with an amplitude between $10r$ and $100r$ (r is the particle radius). With a certain fancy, one can imagine that this is the plane projection of the helical path of the particle, the axis of the spiral being along the magnetic force line. It has been observed that the spiral radius increases with the rise of both the field strength H and the light intensity Φ (Ehrenhaft 1951). If one supposes that a particle carries an electric charge and, at the same time, is a source of magnetic current, the direction of which coincides with the magnetic lines of force, then this fact, at least qualitatively, fits into the framework of the model of electric charge interaction with magnetic current and may become a symmetrical analogue of the experiment described by Mikhailov (1985).

What then is the moving force which forms the basis of the observed effect? We believe the arguments presented in favour of the magnetic charge and against the

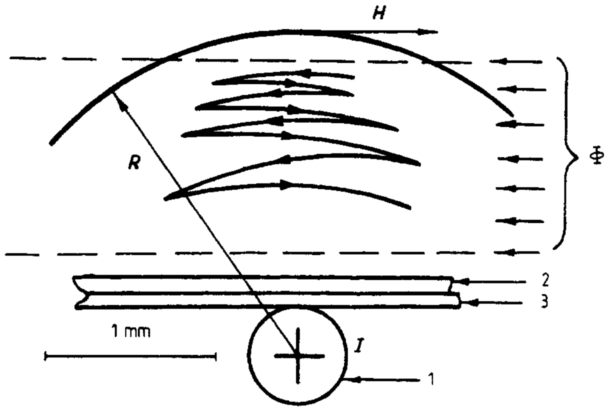

Figure 5. Path of a ferromagnetic particle in the field of a line conductor (1) with a current ($I = 6$ A). The current switching frequency is 3 Hz ($\lambda = 4480$ Å). Copper and glass screens (2 and 3 respectively) are used to prevent gas convection arising from heating of the conductor by the current (Mikhailov 1985, 1987). It is assumed that the transverse component of the velocity is the result of the field interaction with the particle magnetic charge. The radial velocity is the result of the field interaction with the particle magnetic moment.

thermal model are quite convincing. However, there remains one outstanding discrepancy: the value of the elementary magnetic charge, as determined in our work, is less than that of the Dirac monopole (Dirac 1931) by α^2 fold (Mikhailov 1983, 1987) ($\alpha = 1/137$ is a fine structure constant).

Thus there is a serious contradiction between the results of our experiments and present theories of the magnetic monpole.

However, one should note that between the theory and the experiment there is also a contradiction of another kind: searches for the monopoles forceast by Dirac as far back as in 1931 have still not met with success (Carrigan 1983, Incandela 1986).

Nor can one say that there is a common point of view as to the magnetic monopole concept in the framework of theoretical physics either. Alongside with the trend developed in the grand unified models (superheavy monopole with mass $\sim 10^{16}$ GeV), works are known which treat the monopole as a particle with a vanishingly small mass.

Also of interest are studies where the magnetic charge is related to the axial current (Lochak 1985a, b). On the field quantisation this current loses the property or conservation (axial current anomaly) leading naturally to the magnetic charge non-conservation: the introduction of particle creation and destruction operators induced the emergence or disappearance of one sign pair by charge (the conjugation takes place by helicity).

The magnetic charge value, differing from that of Dirac, is obtained in the work of Wang Li (1981, 1986) where the generalised law of electromagnetic charge conservation is derived. The work of Lubomudrov (1984) states in general that the value of the magnetic charge cannot be expressed in principle through the electrical one, but is to be found experimentally.

Akers (1986, 1987) returned to the canonical Dirac mass of the monopole and obtained very interesting results.

This brief survey itself testifies to the absence of any complete generally accepted concept of the monopole and makes us hope that the reconciliation of our experimental results with theory and their interpretation in terms of the magnetic charges are indeed possible. In our studies we found no single fact that could not be explained within the framework of the model with magnetic charge. Moreover, we suggest our own alternative, which eliminates the above-mentioned discrepancy.

5. Reduced value of magnetic charge

Let us follow the behaviour of the monopole with the charge G and mass m in the magnetic field of the particle with mass $M \gg m$ which has a constant dipole magnetic moment $\boldsymbol{\mu}$. Formally, the task amounts to the solution of the Schrödinger steady state equation with the potential

$$U = -\mu \cos \theta / r^2 \tag{18}$$

($\boldsymbol{r}$ is the vector from the particle centre to the situation of the monopole, θ is the angle between $\boldsymbol{r}$ and the magnetic moment axis, r_0 is the particle radius, whereupon $r \gg r_0$). That is,

$$\Delta\Psi + \frac{2m}{\hbar^2}\left(E + \frac{\mu G}{r^2}\cos\theta\right)\Psi = 0. \tag{19}$$

The angular wavefunction, which fits this equation, is as good as the case of the Coulomb field:

$$Y(\theta, \varphi) = P(\theta)\Phi(\varphi) \tag{20}$$

where

$$P(\theta) = P_l^n(x) = (1-x^2)^{|n|/2}\frac{\mathrm{d}^{l+|n|}}{\mathrm{d}x^{l+|n|}}(x^2-1) \tag{21}$$

$x = \cos\theta$ and

$$\Phi(\varphi) = c_1 \exp(\pm \mathrm{i}\, n\varphi) \tag{22}$$

with standard conditions: $P(\theta) \neq 0$ at $|n| \leqslant 1$. From (21) it immediately follows that the monopole can be neither on the field axis ($\theta = 0$) nor on the plane $\theta = \pi/2$.

The equation for the radial function has the form:

$$\frac{r^2}{R(r)}\left(\frac{\partial^2 R(r)}{\partial r^2} + \frac{2}{r}\frac{\partial R(r)}{\partial r}\right) + \frac{2mE}{\hbar^2}r^2 + \frac{2m}{\hbar^2}\mu G\cos\theta = l(l+1). \tag{23}$$

The solution of this equation, provided that $R(r)$ tends to zero as r tends to ∞ (the monopole is in the neighbourhood of the particle pole), has the form

$$R(r) = \frac{c_2}{r}\exp\left[-r\left(-\frac{2mE}{\hbar^2}\right)^{1/2}\right] \tag{24}$$

and the magnetic charge value satisfies the condition

$$G = l(l+1)\hbar^2/2m\mu \cos\theta \tag{25}$$

and the full energy E is indefinite ($E \leqslant 0$).

At short distances from the particle pole the potential in the half-space becomes the Coulomb one $U = -\mu/2r_0 r_c$ where $r_c = r - r_0$. In this case the monopole and the particle make up the bound state with discrete energy levels, and at $r_c = 0$ the wavefunction tends to zero; that is, the monopole is always in the vicinity of the particle pole.

The particle magnetic moment is $\mu = \xi\mu_B$ where $\mu_B = e\hbar/2m_e c$ is the Bohr magneton, and ξ is a non-dimensional number. Then

$$G = \frac{2l(l+1)}{\xi}\frac{m_e}{m}g_D\frac{1}{\cos\theta} \tag{26}$$

and $g_D = e/2\alpha$ is the Dirac monopole charge ($\alpha = e^2/\hbar c = 1/137$).

It is a logical expectation that in our case the orbital quantum number is large. And indeed, if the length of the monopole 'orbit' is $2\pi\rho = l\lambda$, where $\lambda = h/p$ is the de Broglie wavelength, then for a relativistic case

$$l = \rho m_0 c\beta/\hbar\sqrt{1-\beta^2}. \tag{27}$$

For all masses, larger than the electron mass ($m_0 > m_e$) and $1-\beta^2 < 10^{-2}$, at $\rho \sim 10^{-6}$ cm (the value in the order of the particle size), the number $l > 10^6$. This estimate shows that in this case quantum effects will not be dominant. Then, to explain the meaning of relationship (26), it seems useful to simulate the process as follows: the monopole moves along the close flat orbit around the field symmetry axis at a distance from the particle centre equal to $Z = r\cos\theta$.

The components of the dipole magnetic field are:

$$H_\rho = 3\mu\sin\theta\cos\theta/r^3 \qquad H_z = \mu(3\cos^2\theta - 1)/r^3. \tag{28}$$

According to classical dynamics, the condition $Z = \text{constant}$ will be met if $H_z = 0$. Then from the second equation of (28), $\cos\theta = 1/\sqrt{3}$ (and accordingly $\sin\theta = \sqrt{\frac{2}{3}}$) and so

$$H_\rho = \sqrt{2}\,\mu/r^3. \tag{29}$$

Thus, the force acting on the monopole in the plane normal to the axis z (the field symmetry axis) is

$$F_\rho = \sqrt{2}\,\mu G/r^3. \tag{30}$$

The requirement $\rho = \text{constant}$ (orbit stability in its plane) is satisfied by the condition: $mv^2/\rho = F_\rho$ or taking into account that $\rho = r\sin\theta = \sqrt{\frac{2}{3}}\,r$ and extending this condition to the relativistic case, we obtain

$$m_0c^2\beta^2/\sqrt{1-\beta^2} = \sqrt{2}\,\mu G/(\tfrac{3}{2})^{3/2}\rho^2$$

or

$$G = \frac{\rho^2(\frac{3}{2})^{3/2}m_0c^2\beta^2}{\sqrt{2}\,\mu\sqrt{1-\beta^2}} \tag{31}$$

where m_0 is the monopole rest mass.

By substituting the ρ value from (27) and expressing μ through the Bohr magneton, we obtain

$$G = \frac{(\sqrt{3})^3}{4}\frac{l^2}{\xi}\frac{m_e}{m_0}\frac{\hbar c}{e}\sqrt{1-\beta^2}$$

or

$$G = \frac{(\sqrt{3})^3}{2}\frac{l^2}{\xi}\frac{m_e}{m_0}g_D\sqrt{1-\beta^2}. \tag{32}$$

It is evident that formula (32) with good approximation coincides with (26) if in the latter the monopole mass is considered as relativistic and if we keep in mind that, at large values of l, $l(l+1) \simeq l^2$ and $\cos\theta = 1/\sqrt{3}$.

Thus the condition of the bound system formation from the particle with the mass M and the magnetic moment μ and the monopole with the mass $m \ll M$ is the fulfillment of the requirement by which the charge value G must correspond to the values determined from the formulae (32) and (26).

From (32) one can see that

$$G \sim g_D\sqrt{1-\beta^2}. \tag{33}$$

Expression (33) may be the key for realising the origin of the magnetic charge $g \sim \alpha^2 g_D$ (Mikhailov 1983).

It is evident that the 'particle-monopole' system in our experiment manifests itself as an indivisible object having charge G which, according to (33), may be significantly less than the Dirac monopole charge. It is alluring to connect the reason for charge decrease and the relativistic effects caused by the character of motion of a Dirac monopole in a particle field. The postulate is quite realistic, because the Lorentz invariance of a magnetic charge (unlike an electrical one) still waits for its experimental proof.

6. Conclusions

In light of the above, it seems probable that the observed effect—the motion of ferromagnetic aerosol particles in a stationary magnetic field—is due to the interaction between this field and the Dirac monopole producing bound states with the particle.

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